Technical Report 93003

September 1993

Weapons Container Stacking Study

Naval Packaging, Handling, Storage,
and Transportation Center
Naval Weapons Station Earle
Colts Neck, New Jersey 07722-5023

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A study was conducted to determine the maximum safe stack height of fully loaded, free-standing Navy weapons containers when placed in magazine storage. The analysis and calculations used to determine safe stack heights indicate most containers, with adequate structural strength, can be stacked up to 16 feet. A stability criteria was established such that stack heights must be lowered until the displacement at the top of a stack on a 3-degree slope required to cause tip over is greater than 50 percent of the container's stacking width. This report also shows the effects earthquakes could have on a stack of containers. Local authorities are to use this report as a guideline when determining the number of containers they will stack in a magazine.

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Weapons Container Stacking Study

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TABLE OF CONTENTS

Page #

TABLE OF CONTENTS (Continued)

Page

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF TABLES

INTRODUCTION

PURPOSE

This study was conducted to determine the maximum safe stack height of 73 different, fully loaded, free-standing Navy weapons containers when placed in magazine storage. This effort has been requested by Naval Weapons Station Seal Beach as part of PIF92, identified in Missile Storage/ Retrieval System Project S06F92.

BACKGROUND

The ending of the Cold War has brought about a need to better utilize existing magazine storage space. The resulting storage problems came about due to a dramatic reduction in the amount of weapons being stored overseas, the Navy's fleet being downsized, and the Department of Defense reducing the budget for construction of new magazines. As a result of these problems, a new emphasis has been placed on maximum utilization of existing magazine storage space. This increased utilization requires maximizing container stack heights. In most cases, containers have been designed to withstand superimposed loads equal to a 16-foot high stack. Until now, container stability at maximum stack height has not been evaluated.

SCOPE

In the process of determining the safe stacking height for the identified container models, the following items were evaluated:

- The lateral force required to cause sliding between containers
- The lateral force required to tip over the stack
- The lateral displacement required to tip over the stack

The evaluation of these forces and displacement was made under the following conditions:

- On a level floor
- On a floor inclined 3 degrees
- With a lateral force applied 5 feet above floor
- With a lateral force applied near the top of a stack

The recommendation section of this study contains a table showing the safe stacking height for each of the requested containers. In addition, a sample calculation is presented to assist in determining the safe stacking height for new containers or those not specifically addressed in this study.

In addition, the analysis includes calculations of seismic uplift and a chart relating maximum stack height to four different seismic zones in the United States.

METHODOLOGY

PARAMETERS CONSIDERED

The following factors were considered in the study of stacked container stability:

General Container Characteristics

- Identification of Styles

Container Characteristics Considered for Investigation

- Width to Height Ratio
- Stacking Interface Effectiveness
- Weight
- Dimensional Tolerances
- Container Structural Integrity

Storage Site Conditions Considered for Investigation

- Levelness of Floor
- Force and Displacement Applied to Containers
- Seismic Activity

GENERAL CONTAINER CHARACTERISTICS

Identification of Styles

Containers which are the subject of this study are reusable weapons containers consisting of several styles and materials. The style of containers being studied can be described as follows:

- Formed Sheet Metal
- Extruded Sidewall
- External Frame (With Fixed Stacking Arms) and Pod
- External Frame (With Retractable Stacking Arms) and Pod
- Stacking Frame with Skid
- Molded Plastic/Fiberglass
- Wood Crate/Box

A short description of each style is provided below:

Formed Sheet Metal

This type of container is one fabricated from either steel or aluminum consisting of a welded frame, a protective covering of formed sheet metal and a plastic foam/ elastomeric isolation system. (See figures 1 and 2.) This style was prominent in the past and many of these containers are in inventory.

Under this category, the riveted metal container can be considered. This type of container is one having a formed sheet metal shell, an internal frame for structural support, and a plastic foam/elastomeric isolation system. (See figure 3.)

FIGURE 1
Formed Sheet Metal (Mk 372 Mod 7)

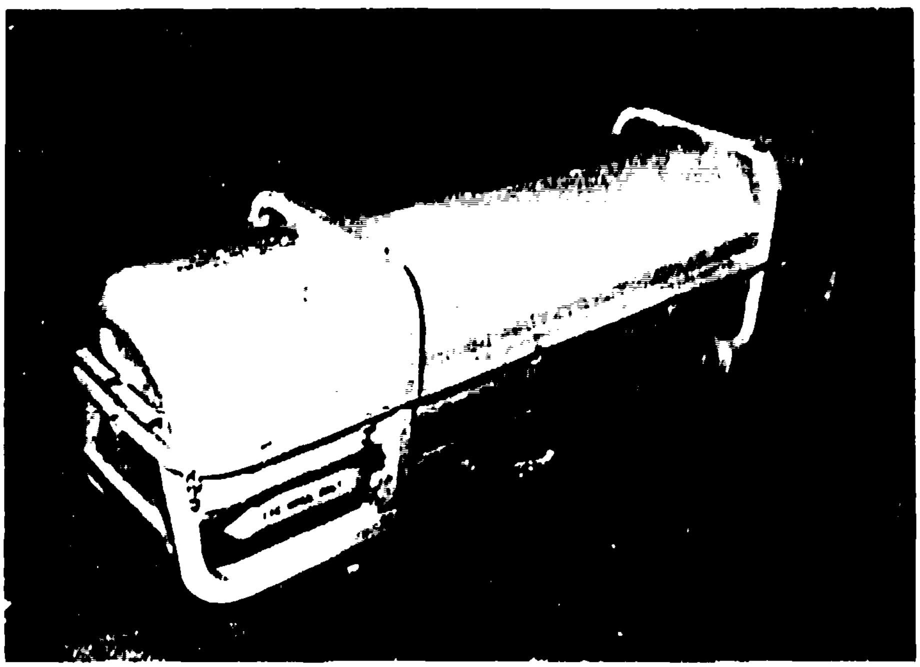


FIGURE 2
Formed Sheet Metal (Typical for Cylindrical Style)

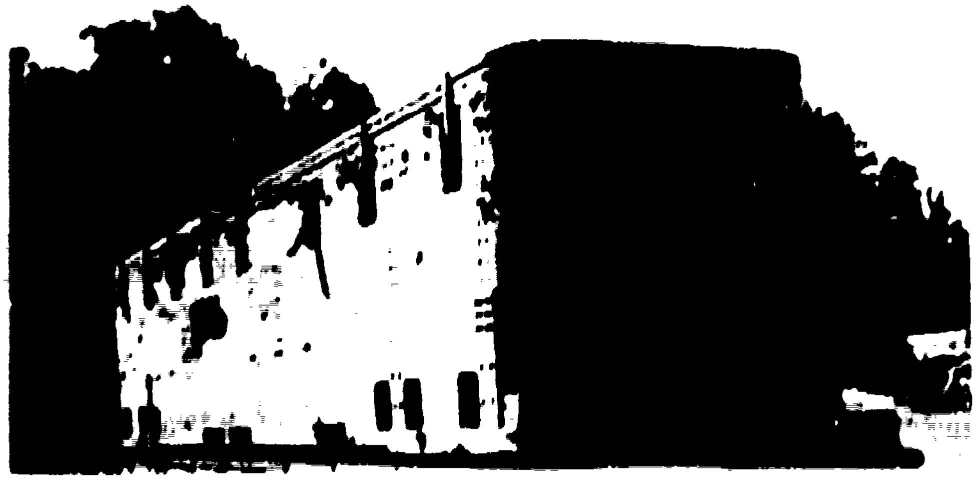


FIGURE 3
Formed Sheet Metal, Riveted (Mk 200 Mod 1)

Extruded Sidewall

This type of container is one fabricated from aluminum, having an extruded shape for the sides and ends with a sheet used for the top and bottom. (See figures 4 and 5.) The isolation system can be plastic foam cushions or a cradle supported by elastomeric mounts. These containers, due to their low cost to manufacture and ruggedness, have been the container of choice for most applications during the last several years.

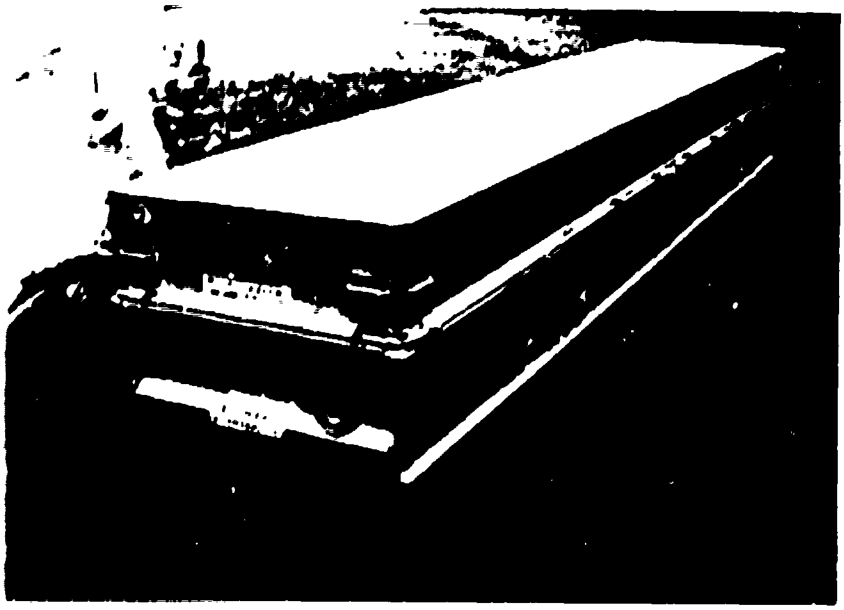


FIGURE 4
Extruded Sidewall (Mk 724 Mod 1)

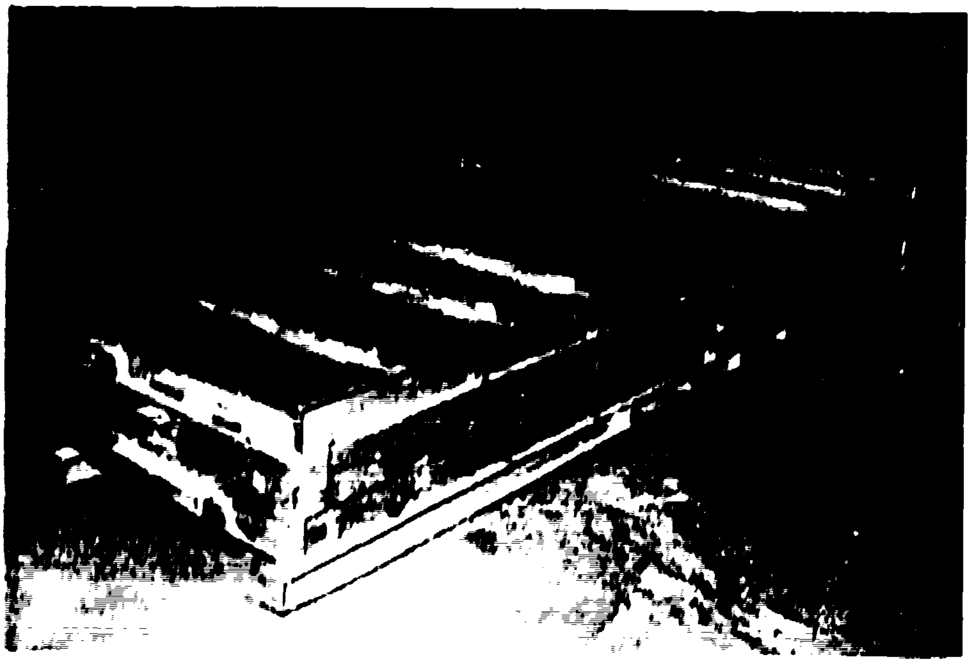


FIGURE 5
Extruded Sidewall (CNU-415A/E)

External Frame (With Fixed Stacking Arms) and Pod

This type of container consists of two major parts, the external frame and a pod or protective shell. (See figures 6 and 7.) The external frame is made of structural aluminum or steel shapes welded into an assembly. The stacking features consist of four fixed height stacking posts. The pod part of the container consists of the weapon support structure covered by a protective plastic or fiberglass shell. The pod is mated to the frame either directly or through elastomeric isolators.

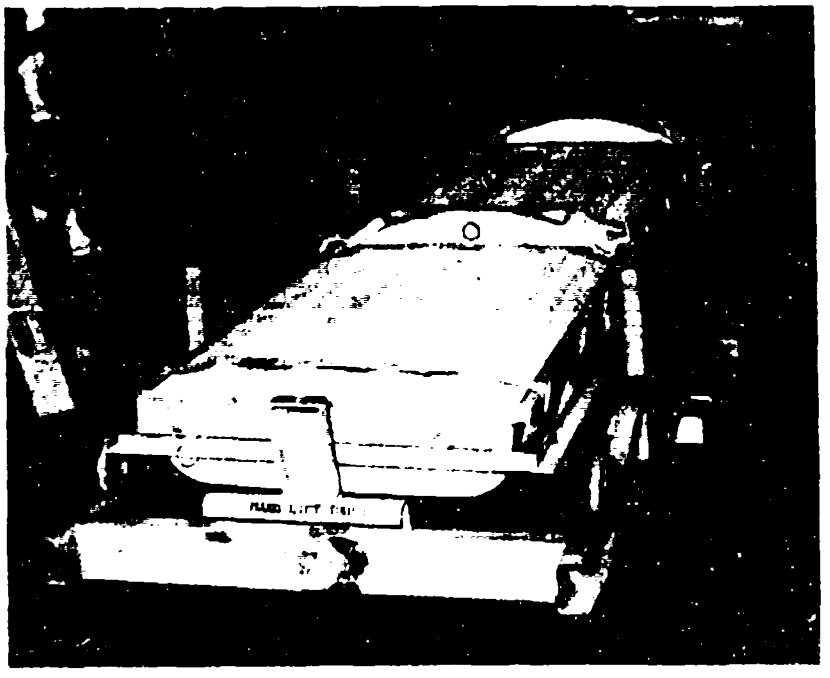


FIGURE 6
External Frame With Fixed Stacking Arms and Pod
(CNU-287/E)

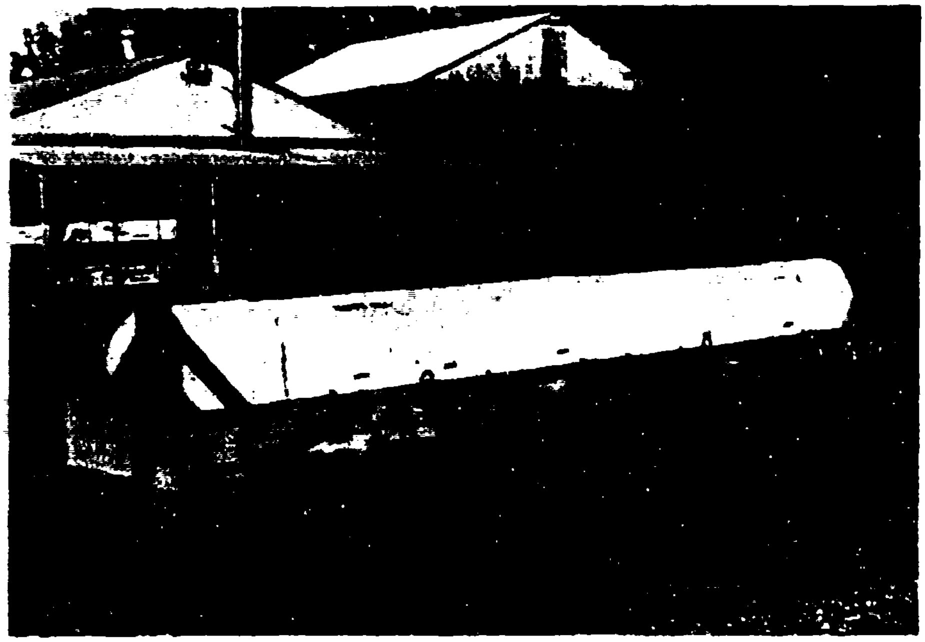


FIGURE 7
External Frame With Fixed Stacking Arms and Pod
(Mk 30 Mod 1)

External Frame (With Retractable Stacking Arms) and Pod

This type of container consists of the same major parts as the previous style. The one additional feature is that the fixed height stacking posts have been replaced by four multi-position telescoping arms. (See figures 8 and 9.) This telescoping feature allows the projecting arms to be retracted down during weapon loading or unloading. In order for the telescoping feature to work consistently, a large amount of lateral play must be designed into the arm assembly.

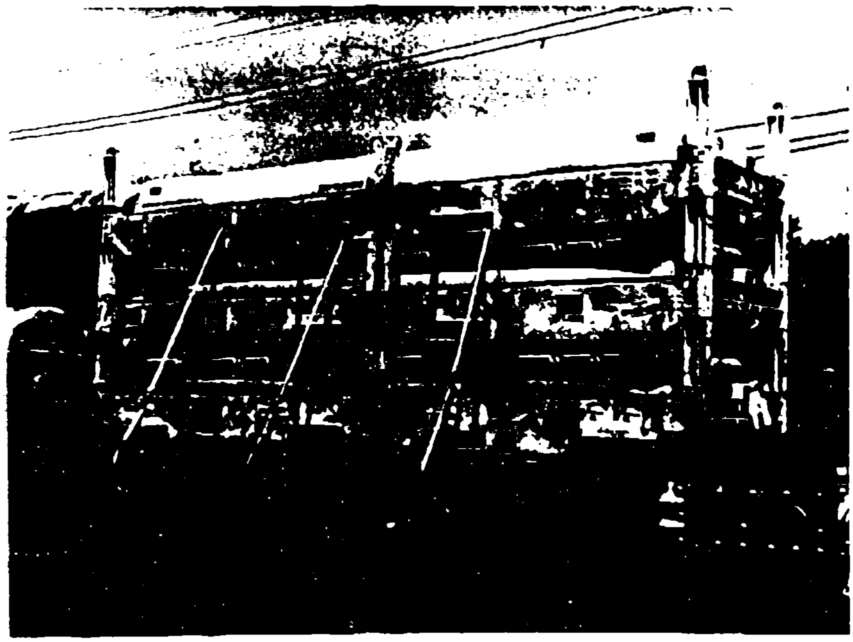


FIGURE 8
External Frame and Pod With Retractable,
Folding Style, Stacking Arms (Mk 14 Mod 0)

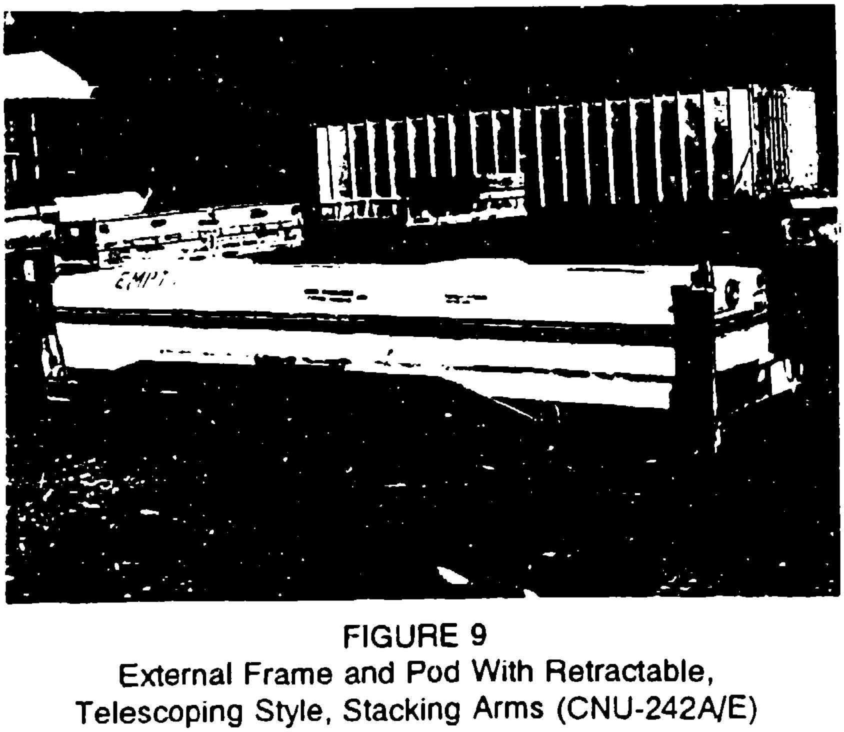


FIGURE 9
External Frame and Pod With Retractable,
Telescoping Style, Stacking Arms (CNU-242A/E)

Stacking Frame With Skid

This type of container uses a metal launch canister as the container with several assemblies being added to facilitate handling, storage, and transportation. (See figure 10.) The assemblies include two shipping skids with elastomeric mounts, two stacking frames with several top mounted locating pins to act as a stacking interlock, and two forklift pockets.

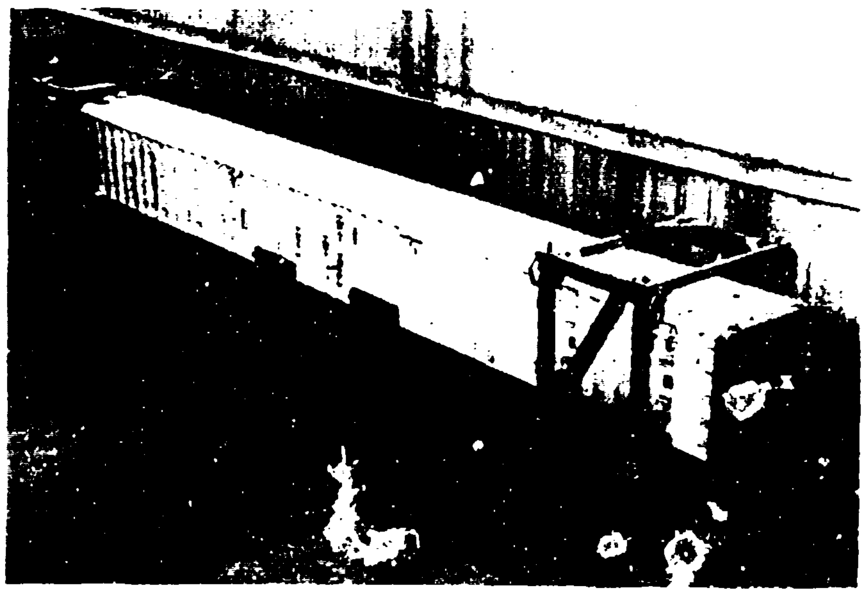


FIGURE 10
Stacking Frame With Skid
(Typical for Mk 13, 14, or 15)

Molded Plastic/Fiberglass

This type of container consists of the cover shell, the base shell, and the isolation system. (See figures 11 and 12.) This style of container has interlocking features molded into the cover and base. The isolation system consists of plastic foam saddles or a support cradle with elastomeric mounts. For this type of container the stacking strength is dependent on the sidewalls of the cover and base shell. Like the formed metal container, this style was widely used in the past with many still in inventory.

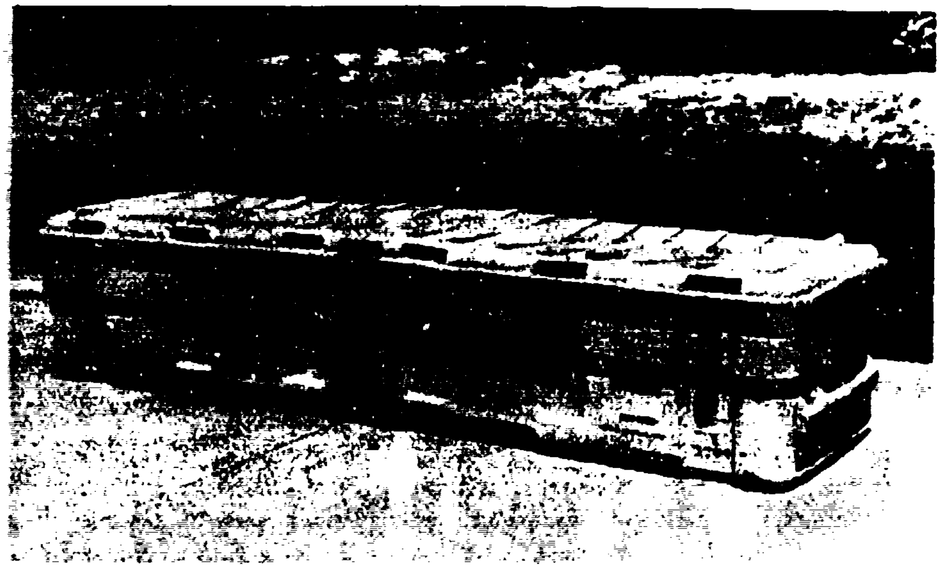


FIGURE 11
Molded Plastic/Fiberglass
(CNU-491/E)

FIGURE 12
Molded Plastic/Fiberglass
(CNU-308/E)

Wood Crate/Box

As the title suggests, this type of container is made using lumber. It is assembled with threaded fasteners, nails, or clips to assure structural integrity. The isolation system, if utilized, consists of plastic foam saddles. Typically, this type of container does not have stacking interlock features. (See figure 13.)

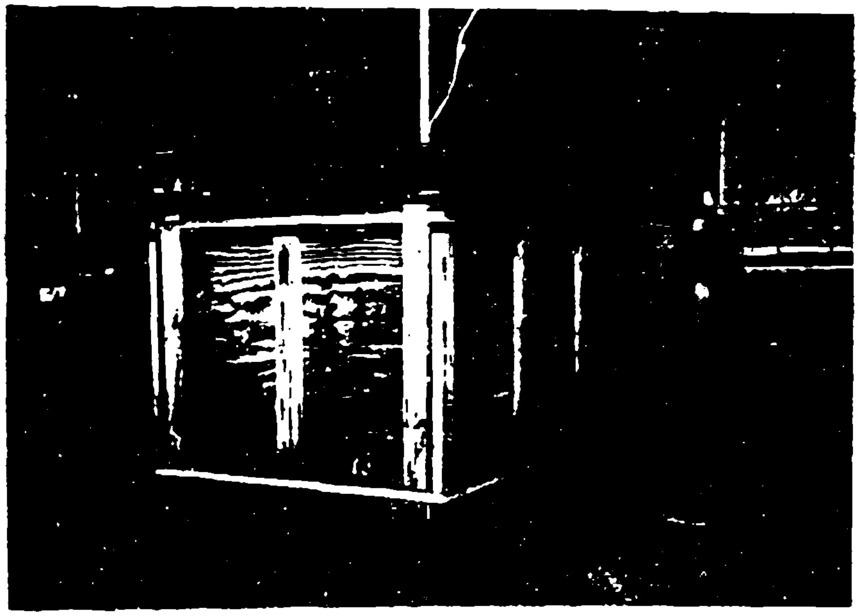


FIGURE 13
Wood Crate/Box (Typical)

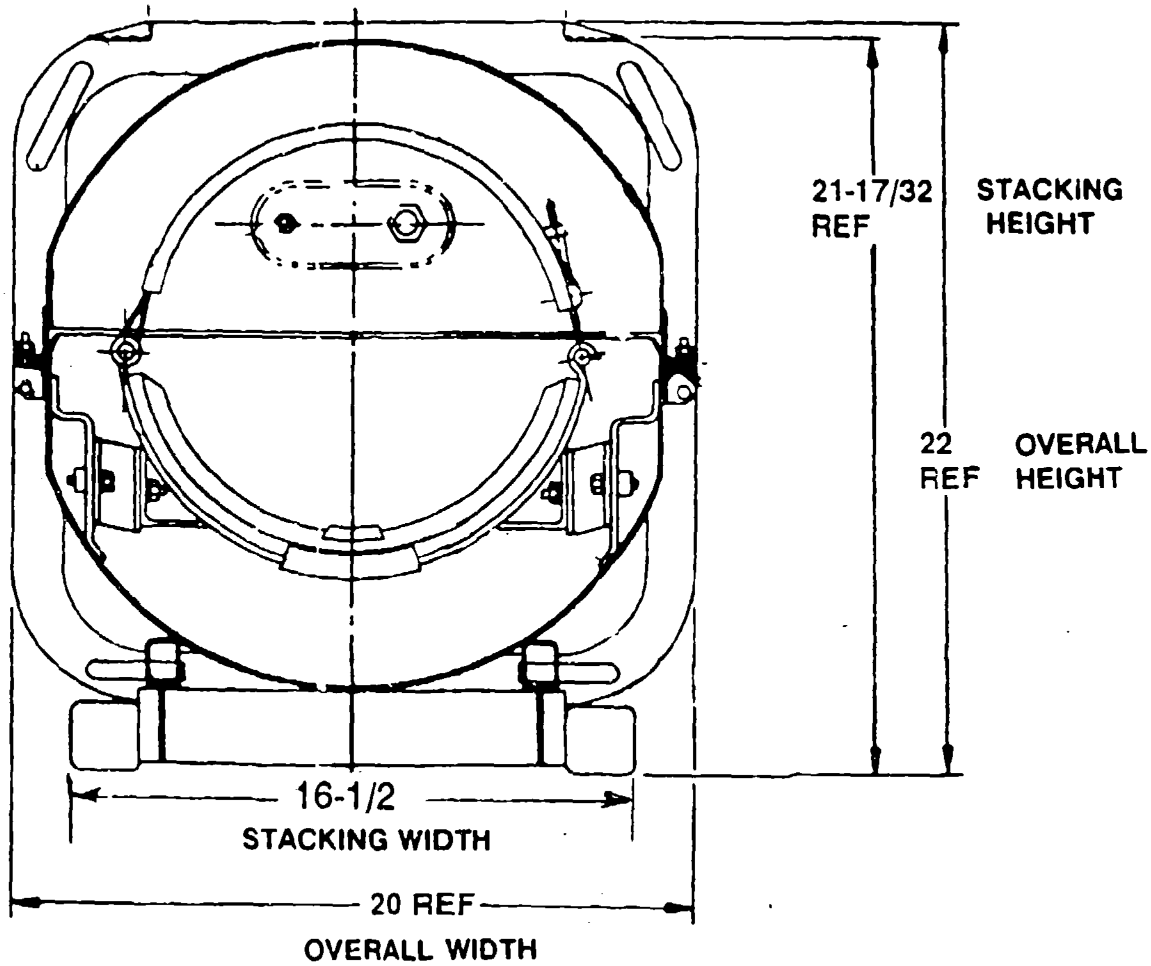
CONTAINER CHARACTERISTICS CONSIDERED FOR INVESTIGATION

Width to Height Ratio

Paramount to the subject of stacked container stability is the width to height ratio. Inherently, a larger width to height ratio results in a more stable container stack. For each of the containers studied, the applicable engineering drawings were examined with the width and height of each being listed in table 1 (Appendix A). The table identifies cases where the container drawings were not readily available. The dimensions used for those containers were supplied by the sponsor of this study. In the table, the container models show two widths and two heights. The first, under each category, is the maximum for the container. The second value, under each category, is located at the container stacking interface. This second dimension will have an influence on stack stability. Depending on the container style, both widths can be the same. Figure 14 illustrates this distinction. Note that for the example shown, the base is narrower than the overall width of the container. This narrowness of interface surfaces results in a condition of reduced stability when compared to other container styles. In addition, depending on style, both the container heights can be identical. For this study the container length is not considered an issue with regard to stability, since a stack will always be less stable laterally than longitudinally.

Stacking Interface Effectiveness

The stacking interface is the method in which containers either nest or interlock with one another when stacked. Its effectiveness in controlling stack stability is primarily determined by the height of the stacking interlock feature. For containers without interlock features, the effectiveness is determined by the combined weight of the containers above and the coefficient of friction between containers. The effectiveness of stacking interface is considered important to container stacking stability. Figure 15 shows a typical stacking interface for an extruded sidewall container design.



MK-197 MOD 1 CONTAINER SECTIONAL VIEW

FIGURE 14
Comparison of Container Overall Versus Stacking Dimensions

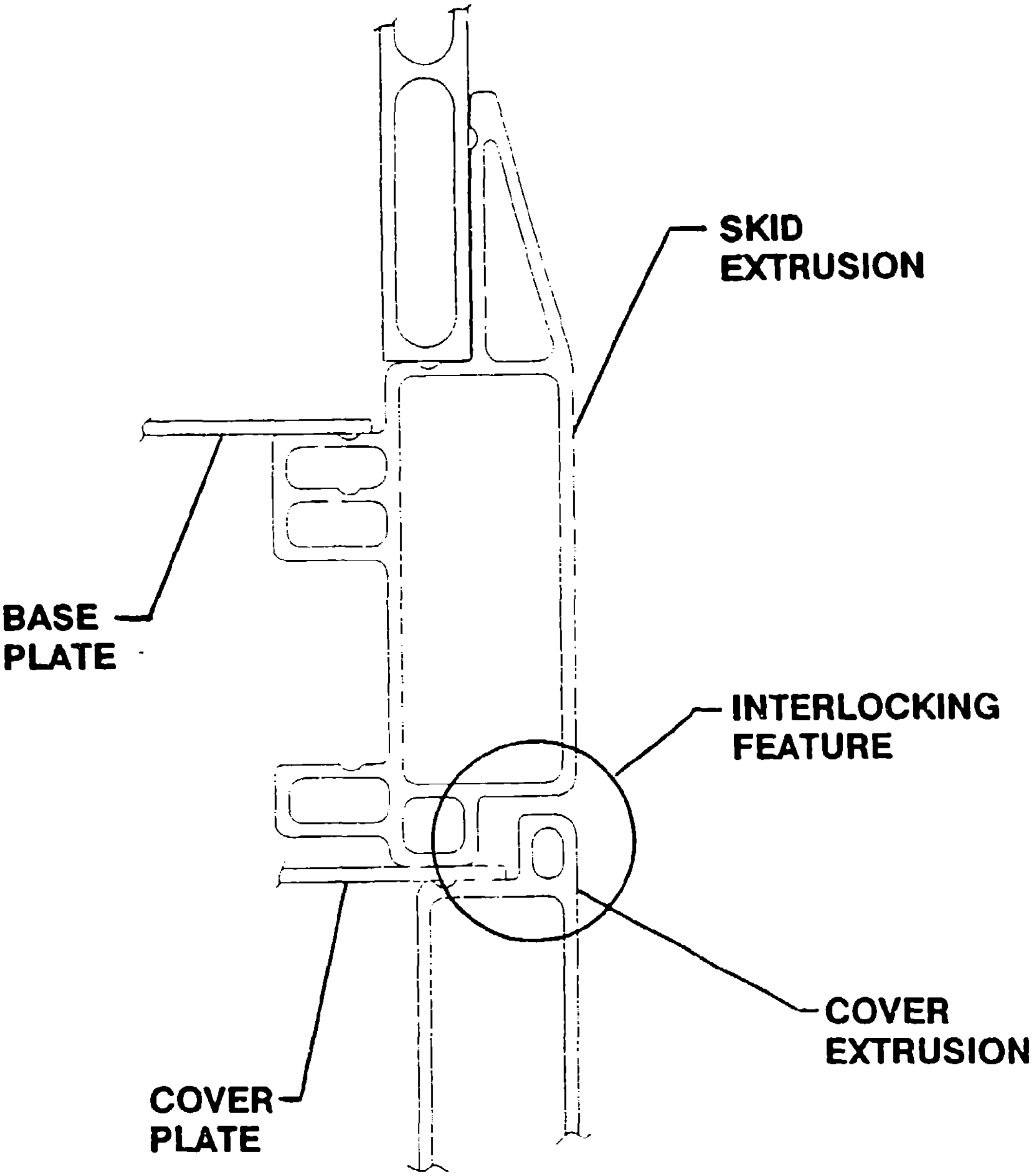


FIGURE 15
Extruded Sidewall Interlocking Feature

Weight

The gross weight for each container being studied, has been listed in table 1. Although gross container weight can vary within the same missile model due to variants (e.g., type of warhead, type of guidance section, etc.) the values presented are representative. The difference in weight between missile variants does not affect the conclusions made in this study. Gross weight of each container is under consideration because it will act as a restoring force to the container stack when external lateral forces are applied.

Dimensional Tolerances

An early part of this study focused on the effect of dimensional tolerances on stacking stability. In theory it was thought, that when a maximum difference of container height tolerances occurred, the stack would lean significantly as the stack grew. (See figure 16.) As a result of the study, it was found that even with the worst possible stack up of height tolerances on a 3-degree sloped floor, an unstable condition would not occur within the magazine height limits. It can be concluded, that dimensional height tolerances are not a limiting factor in container stack stability.

Container Structural Integrity

Container structural integrity is defined as the ability of the container to support superimposed loads without permanent deformation or structural failure. If container geometry would change substantially under this type of loading, the center of gravity for each container can progressively shift away from the geometric center line of the stack resulting in an unstable condition. Because most of the containers being investigated have been tested for conformance with the stacking strength requirements of MIL-STD-648 and FED-STD-101, structural deformation is not considered an issue with stacking stability.

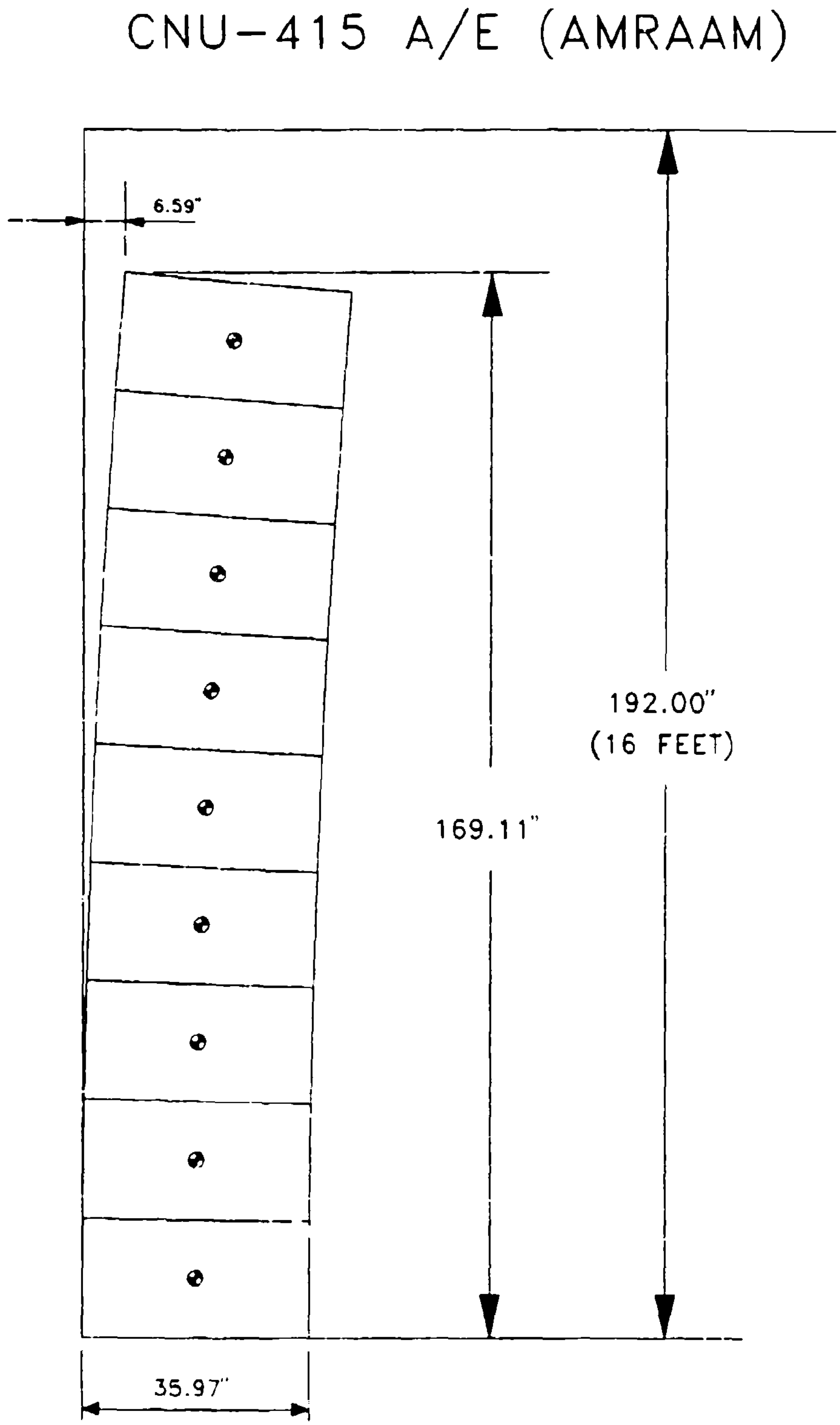


FIGURE 16
Typical Stack Diagram from Dimensional Tolerance Study

STORAGE SITE CONDITIONS CONSIDERED FOR INVESTIGATION

Levelness of Floor

The condition and slope of the surface upon which a stack of containers rests is an important consideration in determining stability. This study assumes that containers would be stacked on a smooth floor without any protrusions or debris which could influence the stack stability. A survey of the typical magazines at Naval Weapons Station Earle indicates that floors can have a slope of 1-1/2 degrees. In recognition that floors at other locations can have a larger slope, a value two times higher (3 degrees) has been selected. Examples presented in this study will include calculations for a container stack on a level floor in addition to a floor having a 3-degree slope.

For those applications exceeding a 3-degree slope, an example and graph has been presented showing the maximum floor angle to topple container stacks of various width to height ratios. (See example 3 and figure 19.)

Force and Displacement Applied to Containers

Since this study is applicable only to containers stacked in enclosed magazines, tip over motion will be caused by contact with forklift truck or personnel. Both types of contact have been evaluated by calculating the force applied or the resulting displacement.

The analysis section of this study uses a lateral force, 5 feet above the floor to simulate the force a person could apply. The lateral displacement required for stack tip over has been calculated at two elevations, 5 feet above the floor, and at the top of the upper most container. The upper most container location is used to simulate forklift truck contact at the top of a stack.

Seismic Activity

Dynamic forces due to earthquakes are a special case since there are a number of variables which will affect container stack stability. Ground waves can be a combination of random and sinusoidal input, producing significant vertical and lateral movement. Additionally, earthquake intensity can vary from event to event and from location to location. Since the study of seismology is a specialized science, assistance to accomplish this phase of the study was sought from the Naval Civil Engineering Laboratory (NCEL), Port Hueneme, California. NCEL responded by supplying a series of calculations showing the effect of various seismic accelerations on a stack of containers. These calculations are presented in the analysis section of this report.

ANALYSIS

The analysis process required presenting the possible modes of stack failure in a logical order. This order begins with the identification of the analysis assumptions, followed by calculations on the basic container stacking limitations and proceeding through each possible mode of non-seismic failure. The analysis section concludes with the development of a stability criteria and calculations on stack limits with seismic activity.

CONTAINER DATA TABLES

To assist in explaining the calculations being presented, table 2 (Appendix A) was developed. This table presents information on the requested containers in order of increasing stacking width.

ASSUMPTIONS

To limit the number of variables requiring consideration, the following reasonable assumptions were made:

- The container center of gravity is located at the container geometric center.
- The weight of the container is uniformly distributed over the volume of the container.
- The maximum available magazine height is 16 feet. This height limit was selected because most of the identified containers have been designed and tested for stacking strength at this value per MIL-STD-648 and FED-STD-101, Method 5016.1.
- Any force under consideration, is applied parallel to the floor.
- The floor does not have any irregularities which would cause rocking of the base container.
- Containers are "Condition Code A" (as defined in MIL-STD-129).
- Containers stacked properly with available interlocking features engaged.
- Containers are placed as a free-standing stack without contacting magazine walls or other container stacks.
- Storage in land-based magazines.
- All multi-round containers are fully loaded.

NON-SEISMIC CALCULATIONS

Maximum Number of Stacked Containers Within 16-Foot Limit (Floor Level, No External Forces)

In the process of analyzing the modes of stack stability failure, it is necessary to define the maximum number of containers possible to be stacked within 16 feet. Figure 17 shows a curve relating the maximum number of containers in a 16-foot stack to the individual container height. The formulas used to develop this curve are shown in example 1. In an actual magazine the stacking height may be limited to a smaller value due to various factors (e.g., overhead lights, column caps, and hoist systems). Because of the possible variations in ceiling obstruction height, all container quantities have been adjusted to fit the top container within the 16-foot limit without allowing for additional space. Column 5 in table 2 presents the maximum stack height, within the 16-foot limit, for each of the containers being studied.

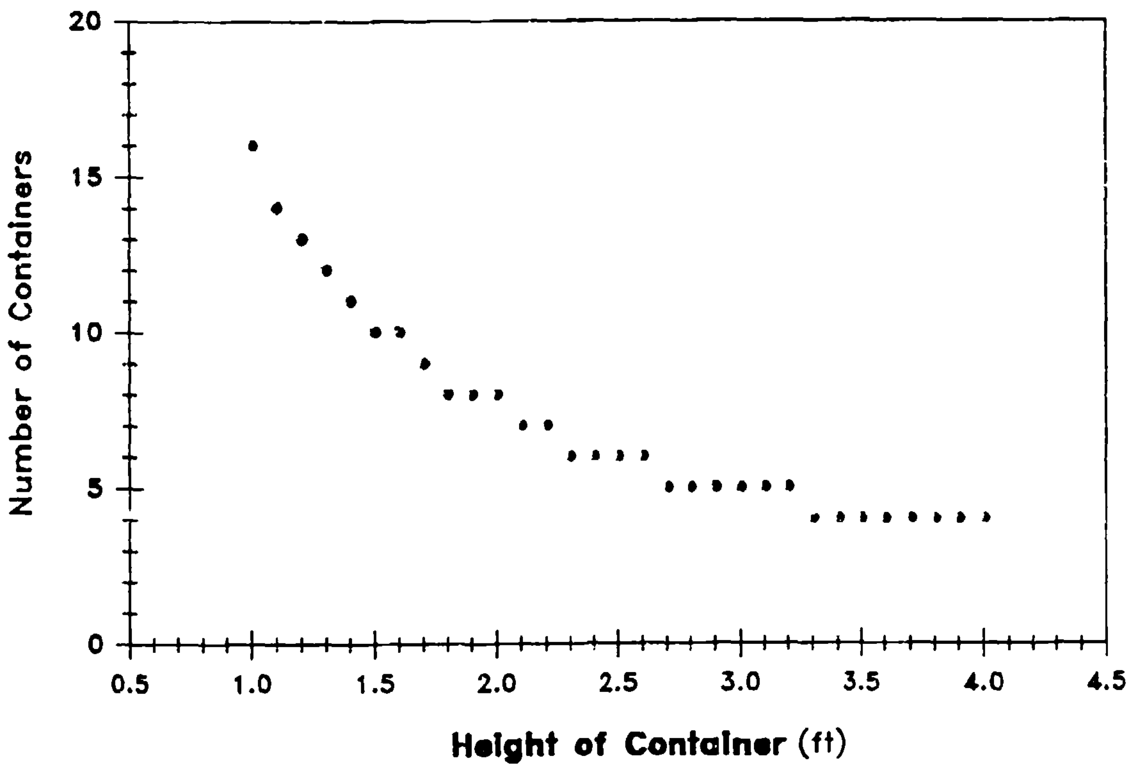


FIGURE 17
Maximum Number of Stacked Containers Within 16-Foot Limit
(Level Floor, No External Force)

EXAMPLE 1
Defining the Maximum Number of Stacked Containers (N) Within the 16-foot Limit (Level Floor, No External Forces)

$$N \equiv \left[\frac{16}{y}\right]$$

where

N - total number of containers in a stack within a 16 foot limit,
y - individual container stacking height in feet,
[ ] - quantity inside the brackets must be truncated to a whole number (e.g., 1,2,3,4 . . . etc.).

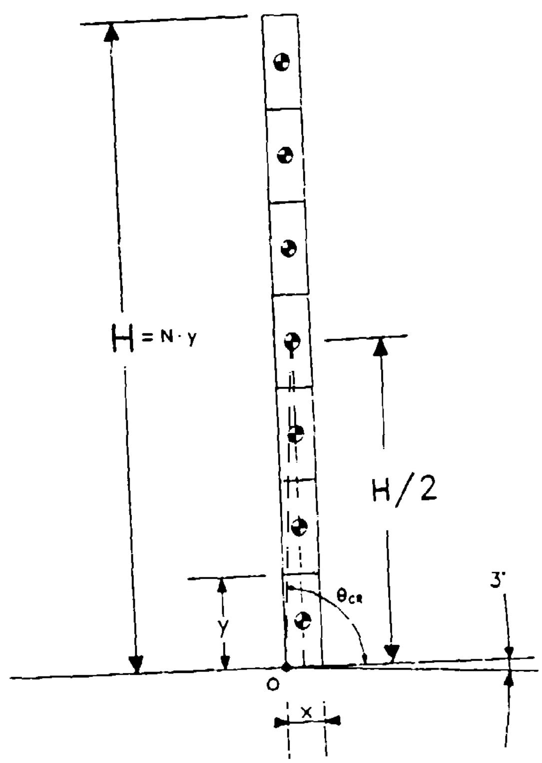
$$\left(\frac{16}{y}\right) - 1 < N \leq \left(\frac{16}{y}\right)$$

Y (ft)	(16/y)-1	(16/y)	N
1.0	15.00	16.00	16
1.1	13.55	14.55	14
1.2	12.33	13.33	13
1.3	11.31	12.31	12
1.4	10.43	11.43	11
1.5	9.67	10.67	10
1.6	9.00	10.00	10
1.7	8.41	9.41	9
1.8	7.89	8.89	8
1.9	7.42	8.42	8
2.0	7.00	8.00	8
2.1	6.62	7.62	7
2.2	6.27	7.27	7
2.3	5.96	6.96	6
2.4	5.67	6.67	6
2.5	5.40	6.40	6
2.6	5.15	6.15	6
2.7	4.93	5.93	5
2.8	4.71	5.71	5
2.9	4.52	5.52	5
3.0	4.33	5.33	5
3.1	4.16	5.16	5
3.2	4.00	5.00	5
3.3	3.85	4.85	4
3.4	3.71	4.71	4
3.5	3.57	4.57	4
3.6	3.44	4.44	4
3.7	3.32	4.32	4
3.8	3.21	4.21	4
3.9	3.10	4.10	4
4.0	3.00	4.00	4

Maximum Number of Stacked Containers Within 16-Foot Limit (Floor Sloped 3 Degrees, No External Forces)

The calculations shown in example 2 define the maximum number of stacked containers before tipping over, on a floor having a 3-degree slope and no external forces. Figure 18 graphs the results. Four dashed line curves represent the stability limits as a factor of width to height ratio. The figure is used by locating the intersection of container height and width to height ratio for a specific container. If the intersection is above the 16-foot limit line, then the stack is limited by ceiling height. If it is below the 16-foot limit line, the stack is limited by stability. In evaluating the containers identified in this study, none fall below the solid line. Therefore, all containers evaluated in this study have their maximum stack height limited by the 16-foot vertical envelope.

EXAMPLE 2
Maximum Number of Stacked Containers (Floor Sloped 3 Degrees, No External Forces)



1. ASSUMPTION

- Floor is sloped 3 degrees.
- Container stack acts as a unit.
- The center of gravity (CG) of the loaded container is at the geometric center of the container.

2. EQUILIBRIUM CONDITION

$$\theta_{cr} = 90° - 3° = 87°$$

$$\tan\theta_{cr} = \frac{\frac{N*y}{2}}{\frac{x}{2}}$$

$$\therefore N = (\frac{x}{y}) * Tan\theta_{cr} = (\frac{x}{y}) * Tan87°$$

$$N = \left[19.08 * (\frac{x}{y})\right]$$

where

N	-	total number of containers in a stack,
x	-	individual container stacking width in feet,
y	-	individual container stacking height in feet,
x/y	-	width to height ratio,
θ_{cr}	-	critical angle for tip over to occur,
[ ]	-	quantity inside the brackets must be truncated to a whole number (e.g., 1,2,3,4 . . . etc.).

After calculating the number of containers "N" for each of the width to height ratios, the following points were plotted as dashed lines on figure 18.

$(\frac{x}{y})$	N
0.5	9
1.0	19
1.5	28
2.0	38

From example 1, the number of containers "N" limited to 16 feet for each of the width to height ratios, was plotted as a solid line on figure 18.

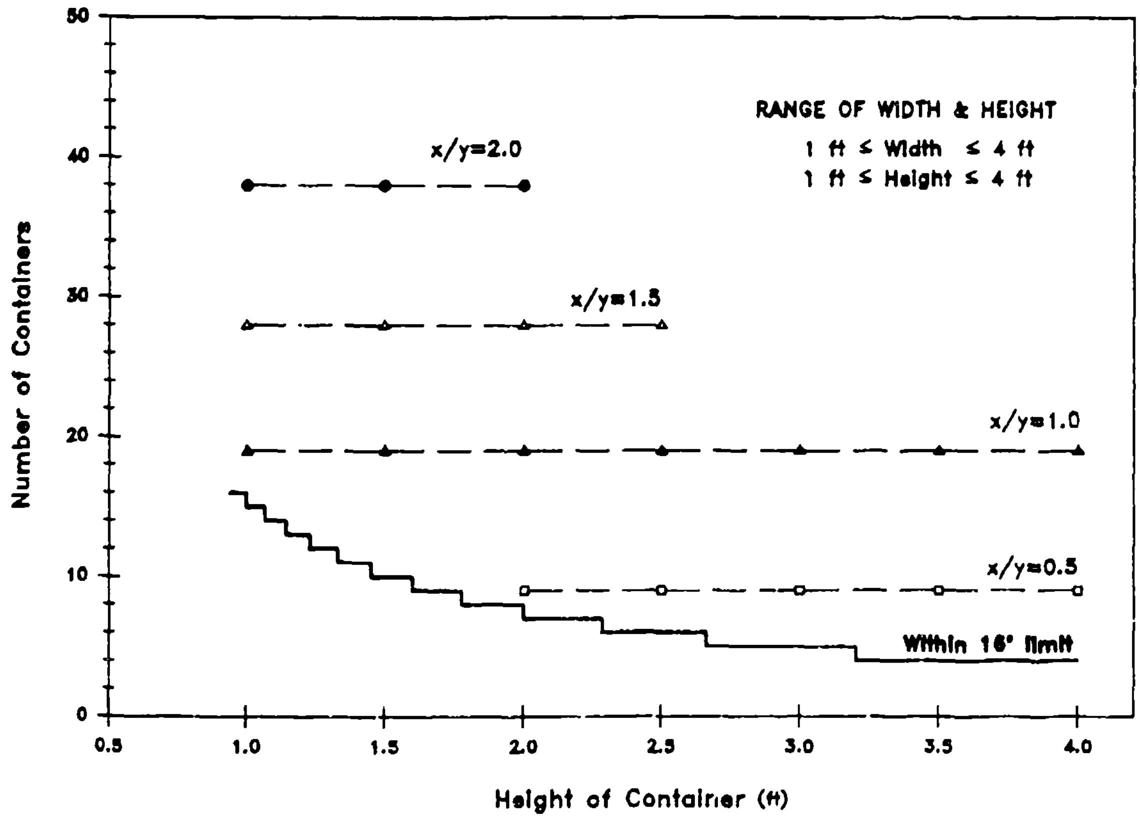
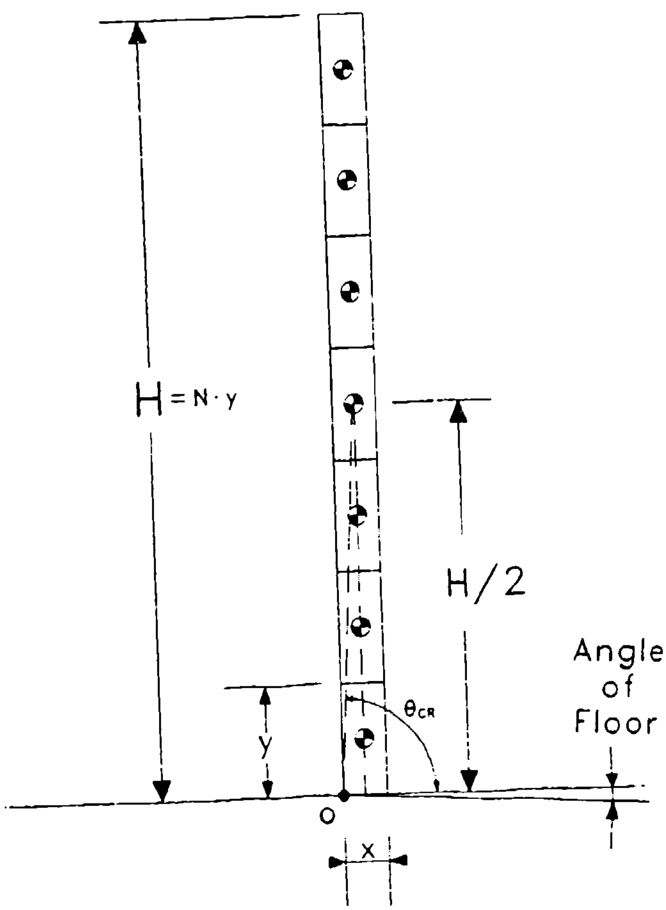


FIGURE 18
Maximum Number of Stacked Containers
On 3-Degree Sloped Floor (Without External Force)

Maximum Floor Angle for a Container Stack, No External Forces

The calculations shown in example 3 and the resulting figure 19 shows the floor angle and number of containers for tipping over to occur as a function of width to height ratio. The curves were calculated for container width to height ratios ranging from 0.5 to 2.0. The range of floor angles shown (3 to 20 degrees) are not practical for real world storage. They have been presented to show that for a constant width to height ratio, the number of containers in a stack must be decreased as the angle of the floor increases to prevent a tip over condition. Column 6 in table 2 presents the maximum floor angle before tip over occurs for each of the containers being studied. This value was calculated using the same equations and limitations as shown in example 3.

EXAMPLE 3
Maximum Floor Angle for a Container Stack, No External Forces



1. ASSUMPTION

- Floor is sloped Θ degrees.
- Container stack acts as a unit.
- The center of gravity (CG) of the loaded container is at the geometric center of the container.

2. EQUILIBRIUM CONDITION

$$\tan \theta_{cr} = \frac{\frac{N*y}{2}}{\frac{x}{2}}$$

$$\therefore N = \left[\left(\frac{x}{y}\right) * Tan\ \theta_{cr} \right]$$

where

N	-	total number of containers in a stack,
x	-	individual container stacking width in feet,
y	-	individual container stacking height in feet,
x/y	-	width to height ratio,
Θ_{cr}	-	critical angle for tip over to occur,
[ ]	-	quantity inside the brackets must be truncated to a whole number (e.g., 1,2,3,4 . . . etc.).

Floor Angle Θ	Number of containers in stack - N					
	3°	5°	10°	15°	20°	25°
(X/Y)- 0.5	9	5	2	1	1	1
1.0	19	11	5	3	2	2
1.5	28	17	8	5	4	3
2.0	38	22	11	7	5	4

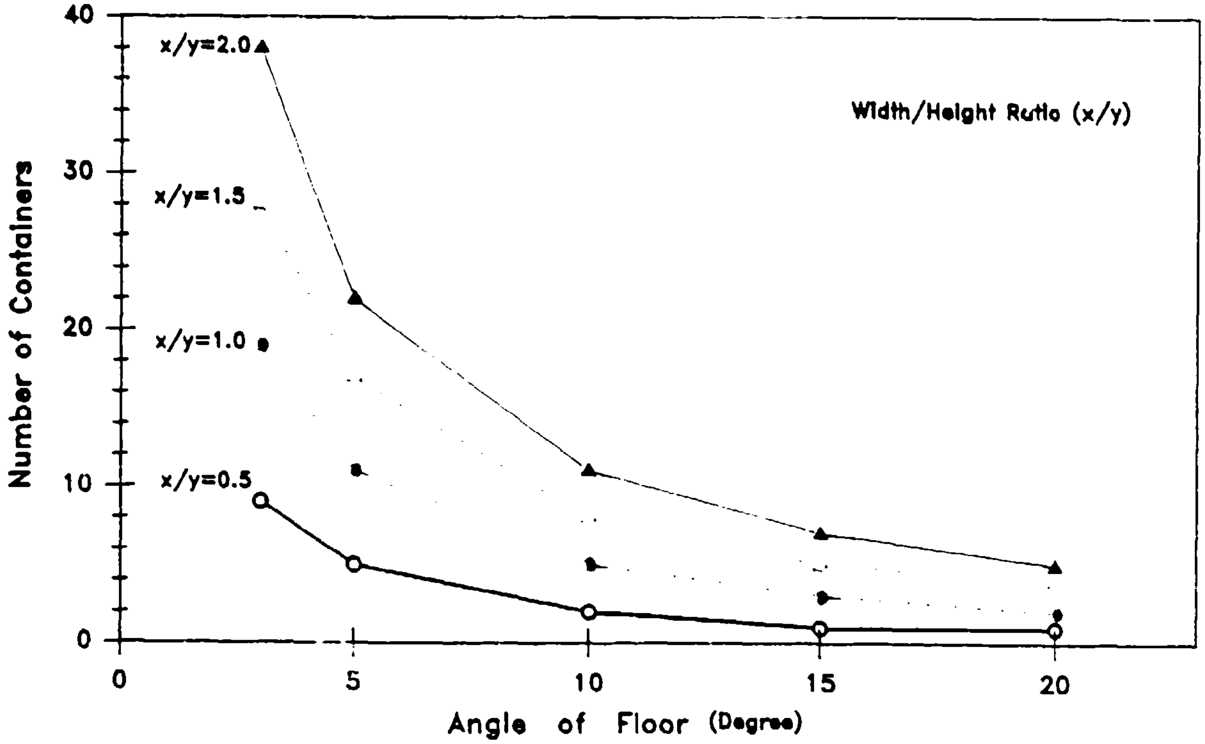
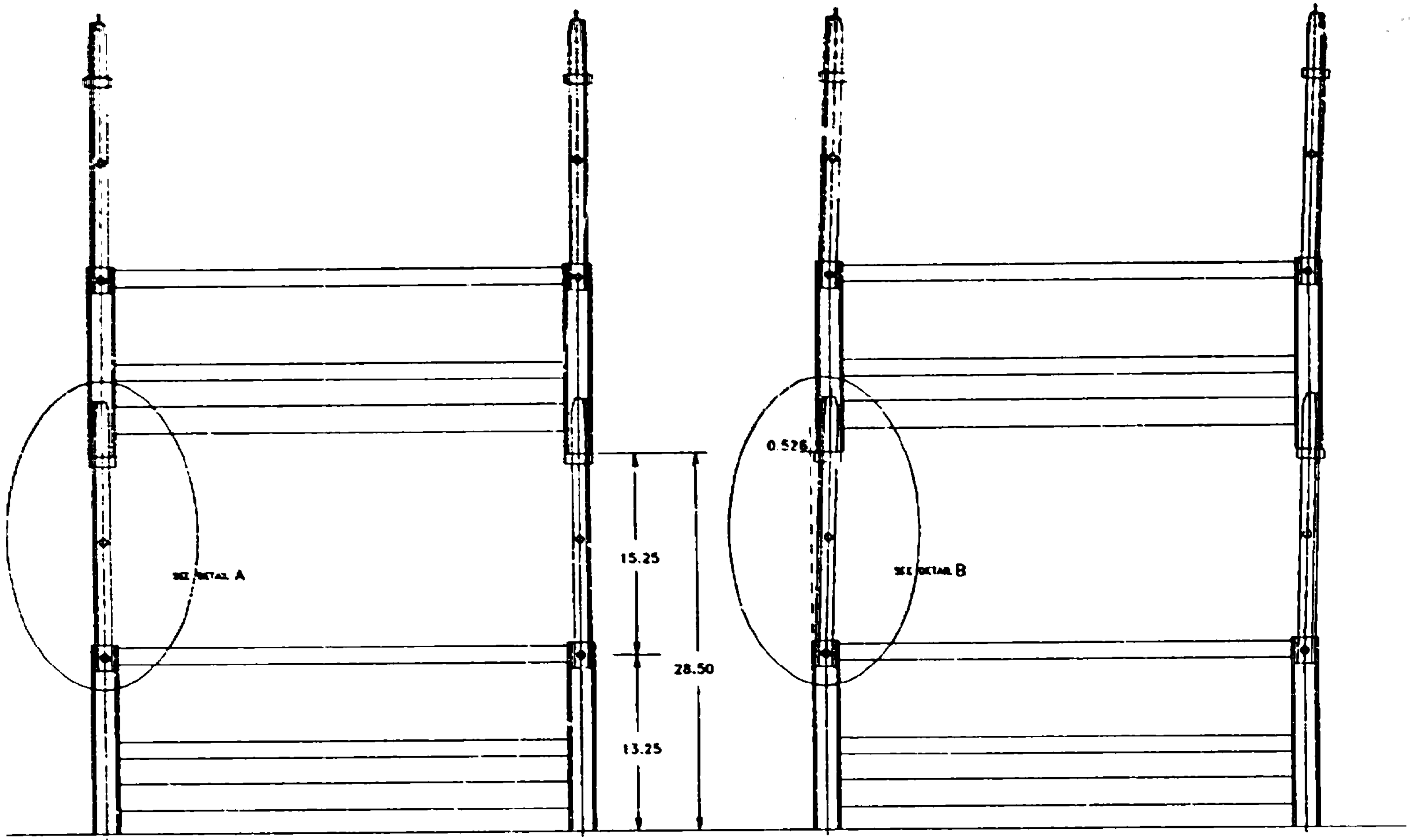


FIGURE 19
Maximum Floor Angle for a Container Stack
(Without External Force)

Lateral Stability for Retractable Stacking Arm Containers

Most of the containers considered in this study, have been mathematically modeled as being rigid in the lateral direction. The one style of container which does not easily fit this criteria are those with retractable stacking arms. As described previously, this feature allows the arms to be retracted down during weapon loading or unloading. In order for the retractable stacking arms to work consistently, an amount of lateral play must be designed into the arm assembly. Figure 20 displays the maximum amount of lateral displacement that could be expected for one style of retractable stacking arm container. For this style, the horizontal surface on the retractable stacking arm and the rigid base of the upper container align. The result is a self-centering action which reduces the amount of lateral play that would occur in a stack. Using the longest stacking arm length of the containers being studied, Detail "A" (figure 21) shows the forces due to weight alone. At this point the forces are vertically aligned. When a forklift truck or person makes contact with the container stack, a lateral force is applied. This force results in a lateral displacement equal to the distance available by the rotation of the stacking arm. Upon removing the applied lateral force the weight forces are misaligned as shown in Detail "B". The misalignment of the weight forces results in a restoring moment acting about the lower container stacking arm pivot point. This restoring moment returns the stacking arm to its original position where the weight forces are aligned. As the equations in Detail "B" indicate this restoring moment increases as the weight above the interface increases. A test performed at the PHST Center on a stack of six PHOENIX CNU-242A/E Containers verified this theory. A videotape was taken recording this test. The self-centering action described should be representative for all retractable stacking arm containers.

In addition to the self-centering action, another factor controlling stack stability is container width. Containers of this style are some of the widest requested for this report. The containers in question are located in table 2 within the group having a stacking width ranging from 36 to 38 inches. To prove the stability, the following calculation was performed on the container shown in figure 20. When this container is stacked eight high, and a lateral force is applied at the top, the top of the stack can be displaced 4.21 inches without the base pivoting. From table 2 (column 9, item no. 62) it can be seen that 4.21 inches displacement is less than the displacement at tip over (27.71 inches). While it appears that the retractable stacking arm style of container will form an unstable stack, calculations and testing indicate the opposite.



NORMAL STACKING

MK 607 MOD 0 (HARPOON)

LIMITED LATERAL DISPLACED STACKING

0.526" PER STACK

FIGURE 20
Typical Retractable Stacking Arm Container Before and After Applying a Lateral Displacement

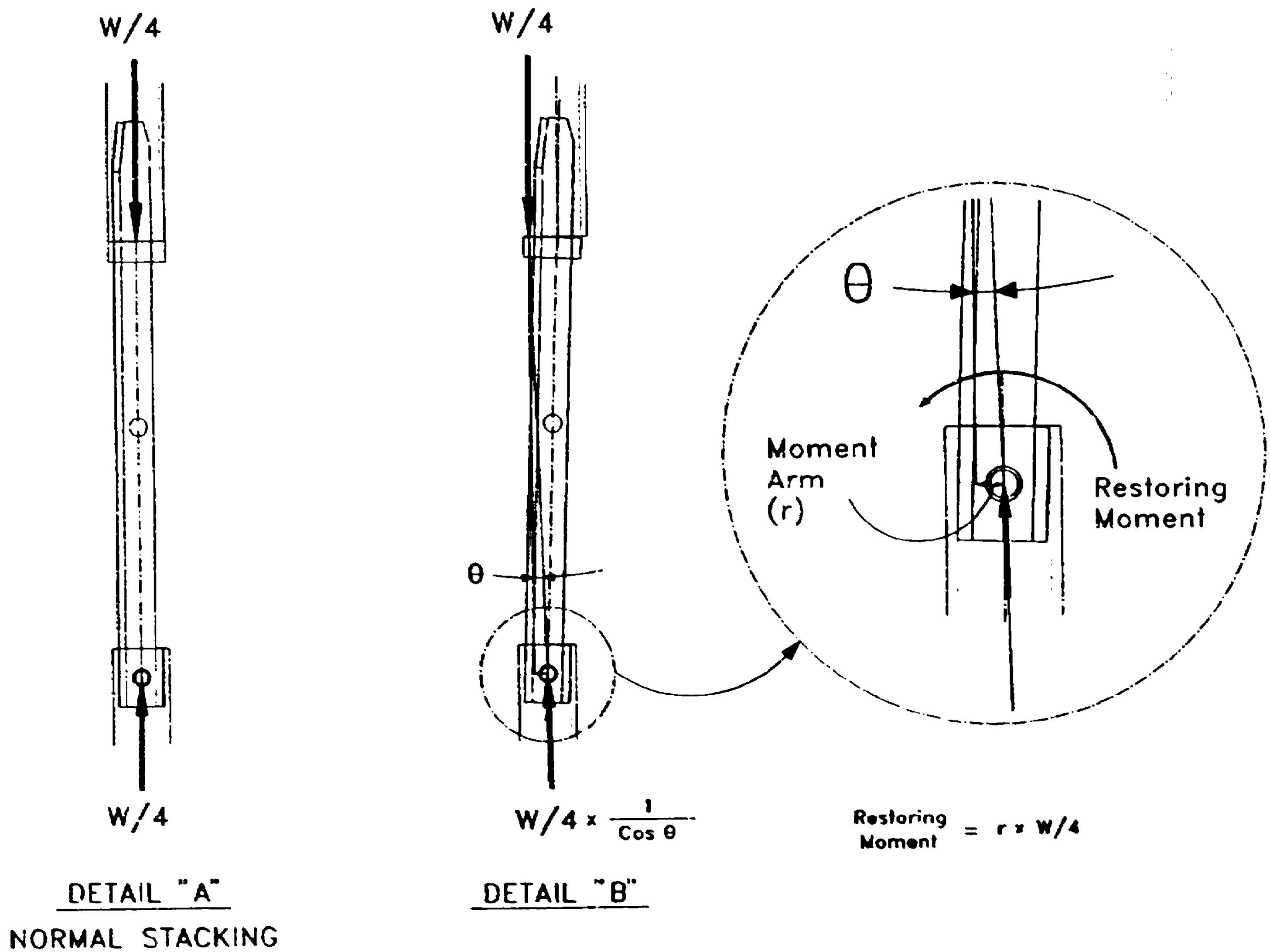


FIGURE 21
Details Showing Self-Centering Mechanism for Typical Retractable Stacking Arm

Possible Modes of Stack Failure

The next area under consideration, was container stack height with external forces being applied. Before calculations could be performed the modes of stack failure needed to be defined. It was determined that stack failure could occur in one of three ways. The first mode was containers sliding on containers. The second mode was a stack of containers tipping over at the interface between the stack base and floor. The third mode was a combination of sliding and tipping at any interface level between containers. Figure 22 shows each of these failure modes.

The application of forces necessary to cause any of the above failure modes was determined next. In a magazine, an assumption was made that forces could be applied in one of two ways. The first is that in maneuvering, a forklift could inadvertently contact a stack of containers. This accidental contact could occur either upon placing a container on a stack without a spotter or upon removing the fork tines at an angle after container placement. The second method in which toppling forces could be applied, is with storage personnel leaning or pushing against a stack.

Resolving the issue of contact between a forklift and the container stack meant defining vehicle speed at contact, vehicle mass, whether brakes were applied, surface condition of the magazine floor, and operator response time. While all of these factors exist, "how far" the forklift displaces the stack is considered to be the most important parameter. Whether the forklift is traveling at 2 miles or 2 feet per hour, the stack will eventually be displaced far enough beyond the point of stability that it will tip over. For this reason, minimum displacement to tip over was used as a criteria in the analysis. The elevation for this calculation was the distance from the floor to the top of the upper-most container in a stack.

Resolving the issue of storage personnel leaning or pushing against the stack meant defining a range of shoulder heights and the maximum force a person could apply. It was determined that all calculations be performed using a force being applied at 5 feet above the floor. The maximum amount of force a person can apply from shoulder height was found in MIL-HDBK-759B (table 51). In that table, the horizontal force a person can apply through one shoulder while standing on a high traction surface (μ = .9) was identified as 310 N (67.9 pounds).

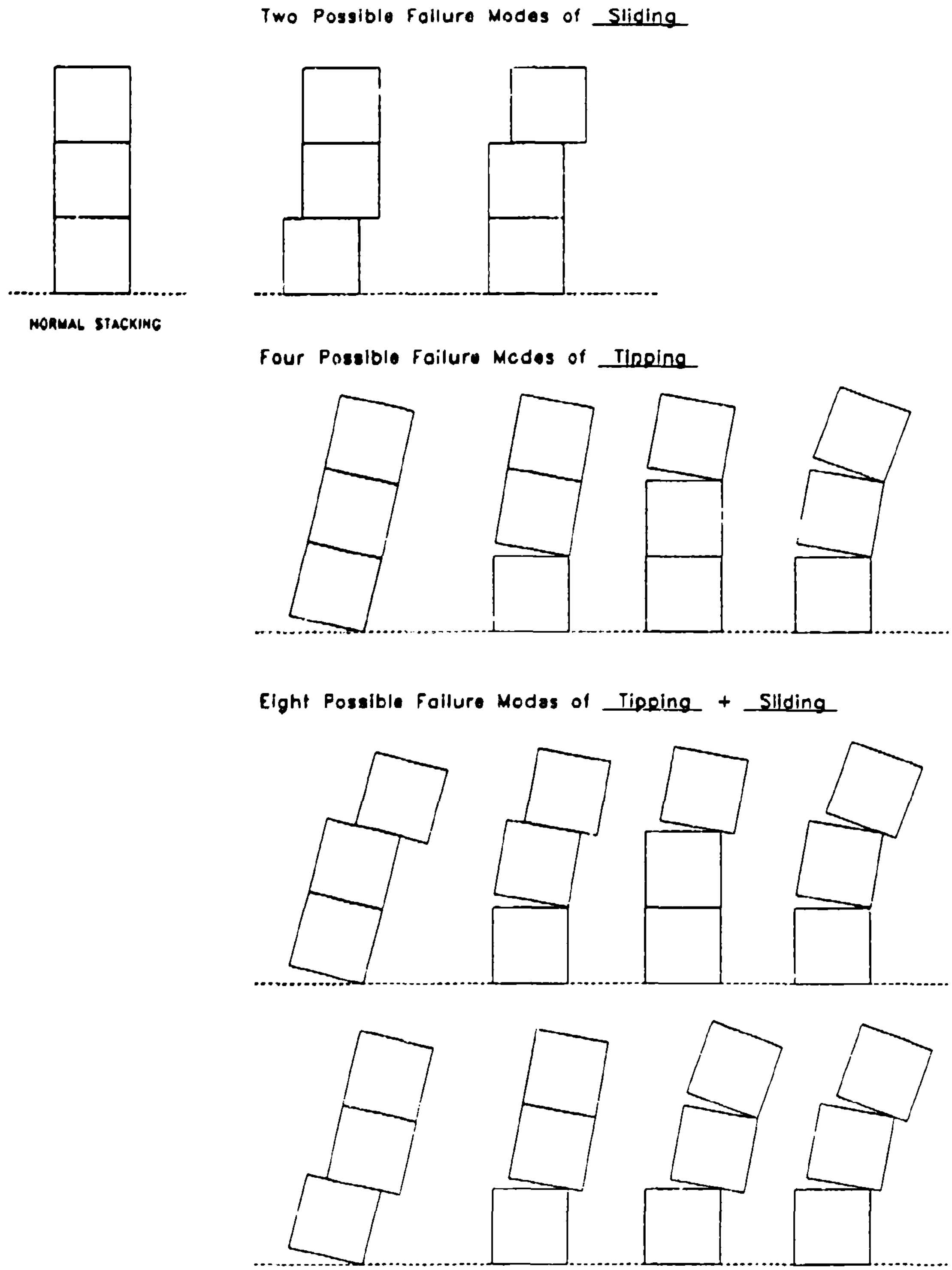
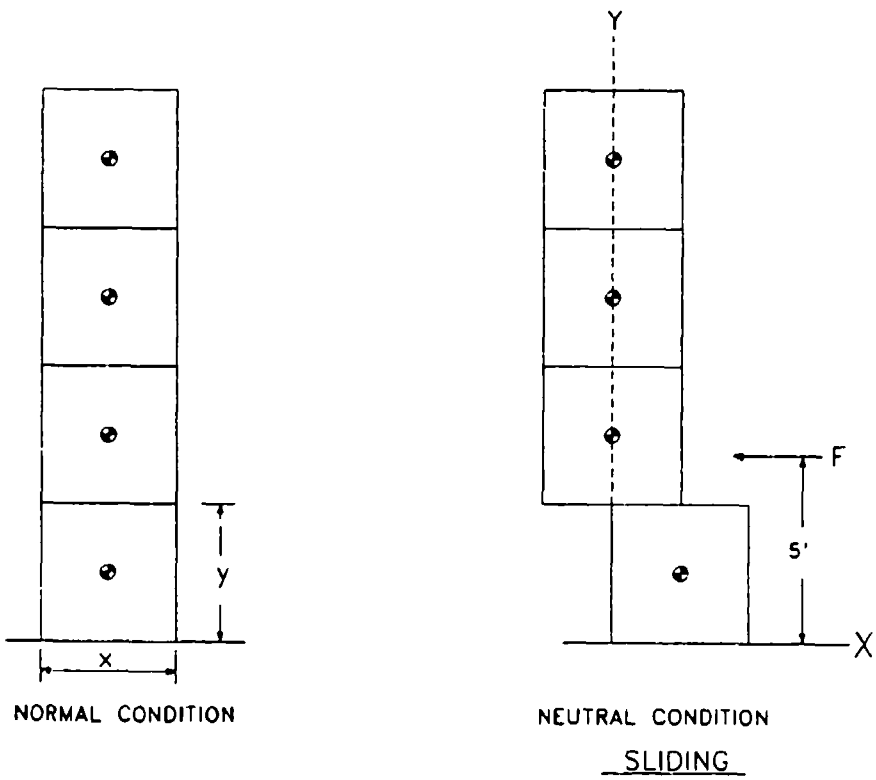


FIGURE 22
Possible Modes of Stack Failure

Minimum Sliding Force Required for Several Types of Container Materials

The calculations shown in example 4 demonstrates how the coefficient of friction between container interface surfaces affects the minimum sliding force. The coefficients range from 1.05 for aluminum on aluminum to 0.27 for plastic on plastic. The friction coefficient for plastic on plastic was obtained from PET (Polyethylene Terephthalate) plastic. The use of this value was suggested by Owens Corning Fiberglass to simulate the gel coat surfaces on fiberglass containers. It has been assumed that the woven glass fabric does not add any surface roughness to the gel coat.

EXAMPLE 4
Minimum Sliding Force Required for Several Types of Container Materials



The force required to slide a container

$$F = \mu_s * P = \mu_s * (n * W)$$

using

μ_s	=	1.05 for aluminum on aluminum
	=	0.74 for steel on steel
	=	0.70 for steel on wood
	=	0.60 for wood on wood
	=	0.27 for plastic on plastic

$$F = \mu_s * \left([\frac{16}{y}] - [\frac{5}{y}] \right) * W$$

where

F	=	required force in pounds,
n	=	number of containers above the slip plane,
P	=	normal force to slip plane,
W	=	weight of individual container in pounds,
y	=	height of individual container in feet,
μ_s	=	static friction coefficient,
[ ]	=	quantity inside the brackets must be truncated to a whole number (e.g., 1,2,3,4 . . . etc.).

Y (ft)	$F_{sliding}$ in multiples of container weight (W)				
	$\mu_s = 1.05$	$\mu_s = 0.74$	$\mu_s = 0.70$	$\mu_s = 0.60$	$\mu_s = 0.27$
1.0	11.55	8.14	7.70	6.60	2.97
2.0	5.25	3.70	3.50	3.00	1.35
3.0	4.20	2.96	2.80	2.40	1.08
4.0	3.15	2.22	2.10	1.80	0.81

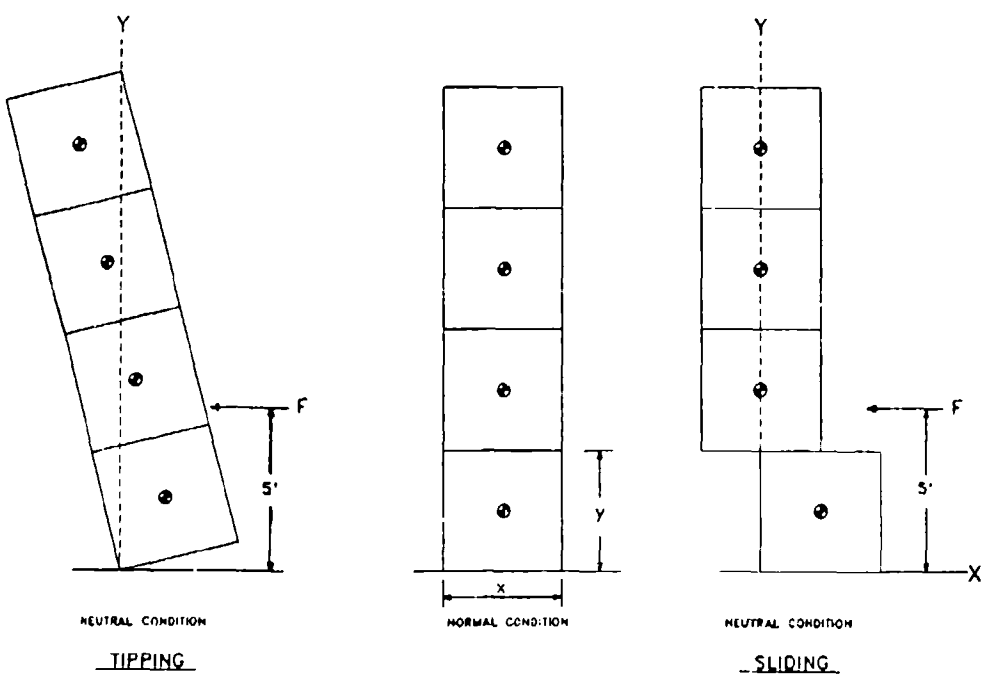
Comparison of Sliding vs. Tip Over Force

Example 5 presents calculations comparing the force required to slide aluminum on aluminum versus the force required to tip over a stack of containers. In each case, the restraining action of stacking interlocks has not been considered. The calculations show that the force required to tip over a container is less than the sliding force. At the end of this sample calculation, the case of plastic on plastic is also presented. The calculation using this material shows that the force required to slide is less than the tipping force.

The calculations also show that for most container materials studied tipping is the dominant mode of failure. The exception is for containers made of low coefficient of friction materials (e.g., plastic or fiberglass) where sliding could be the dominant mode of failure depending on the width.

Figure 23*A* thru *E* displays the tipping force vs. sliding force, for each of the coefficients of friction. An examination of figures 23*A* thru *D* indicates that the tipping over force is less than the sliding force. The curves in figure 23*E* (plastic on plastic) shows that for container widths greater than 2 feet, the force required to slide is less than the force required to tip. For those container widths, even though sliding can occur first, the effect can be ruled out if stacking interlocks exist.

EXAMPLE 5
Comparison of Sliding vs. Tip Over Force



Tipping	Sliding
$\Sigma M_{Tipping} = 5' * F \quad \Sigma M_{Restoring} = (\frac{x}{2}) * (N * W)$	
Equilibrium Condition $\Sigma M_{Tipping} = \Sigma M_{Restoring}$	$F = \mu_s * P$
$5' * F = (\frac{x}{2}) * (N * W)$	
Substituting for "N" $F = (\frac{x}{10}) * W * [\frac{16}{y}]$	Substituting for "P" $F = \mu_S * (n * W)$
	Substituting for "n" $F = \mu_S * ([\frac{16}{y} - 1] * W)$
where F = required force in pounds, W = weight of individual container in pounds, x = individual container width in feet, y = individual container height in feet, [ ] = quantity inside the brackets must be truncated to a whole number (e.g., 1,2,3,4 . . . etc.), N = total number of containers within 16 ft limit and truncated to a whole number.	where F = required force in pounds, μ_s = static friction coefficient (from example 4), P = normal force to slip plane in pounds, n = number of containers above the slip plane, W = weight of individual container in pounds, y = individual container stacking height in feet, [ ] = quantity inside the brackets must be truncated to a whole number (e.g., 1,2,3,4 . . . etc.)

Tipping	Sliding
For example x = 3.63 feet y = 3.69 feet F = 1.452 * W	Using the same container dimensions as in tip over example For example n = 3 For aluminum on aluminum $F_{Friction}$ = 1.05 (3 * W) = 3.15*W For plastic on plastic $F_{Friction}$ = 0.27 (3 * W) = .81*W

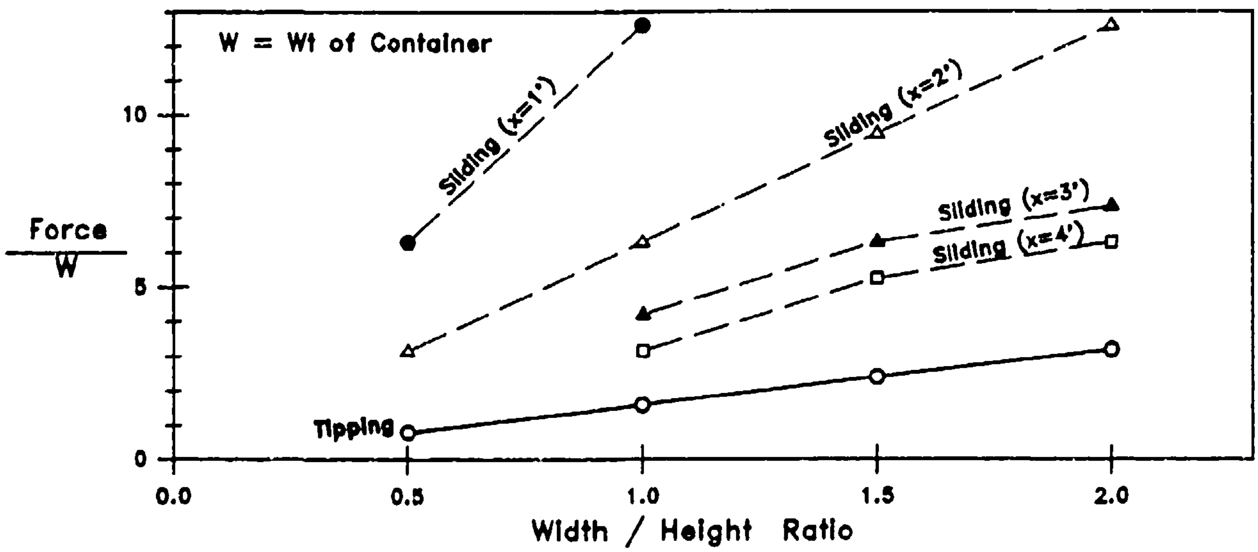


FIGURE 23A
Tipping vs. Sliding Force (μ=1.05, Aluminum-Aluminum)

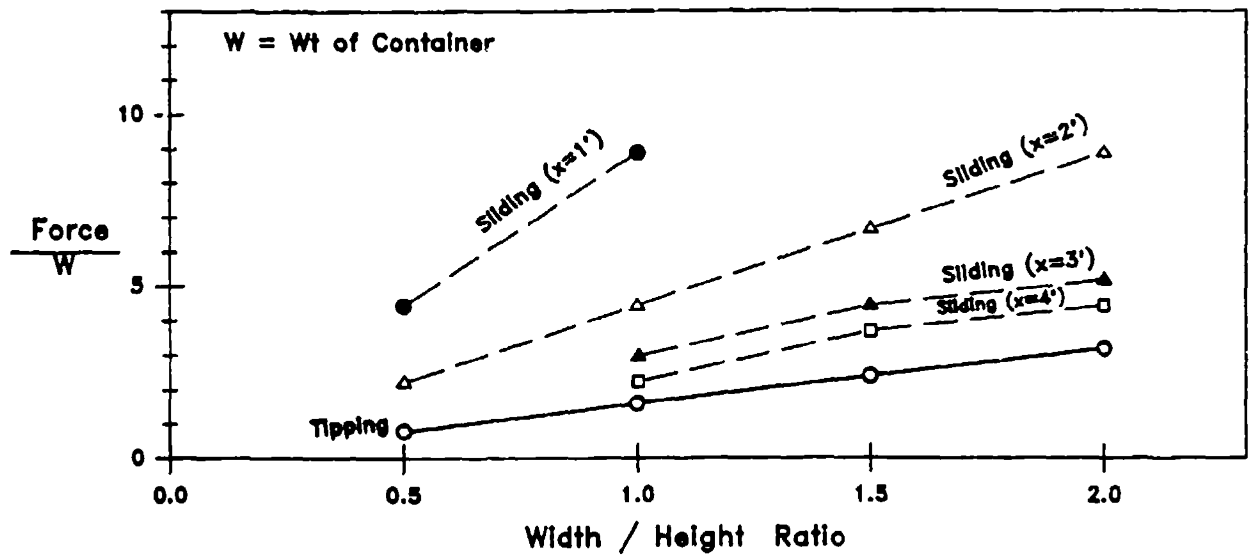


FIGURE 23B
Tipping vs. Sliding Force (μ=0.74, Steel-Steel)

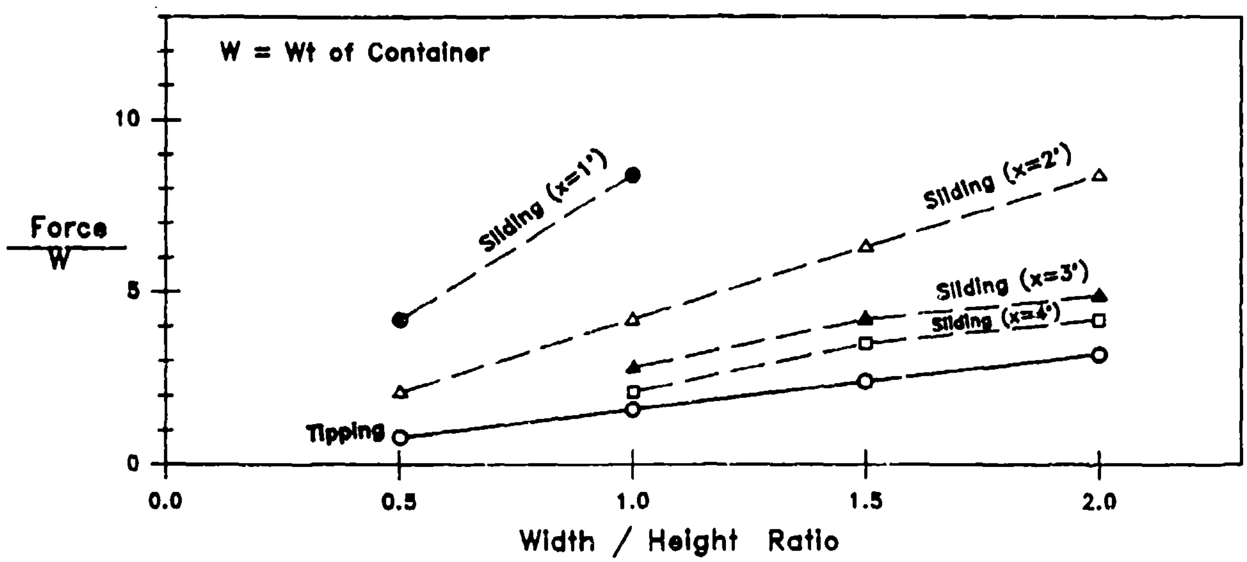


FIGURE 23C
Tipping vs. Sliding Force (μ=0.70, Steel-Wood)

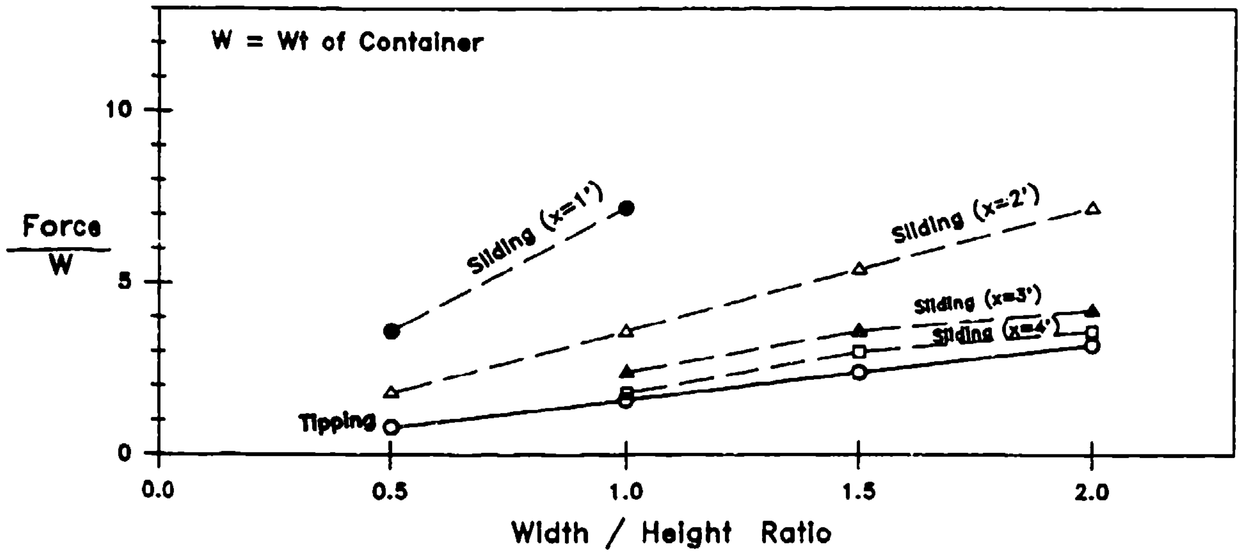


FIGURE 23D
Tipping vs. Sliding Force (μ=0.60, Wood-Wood)

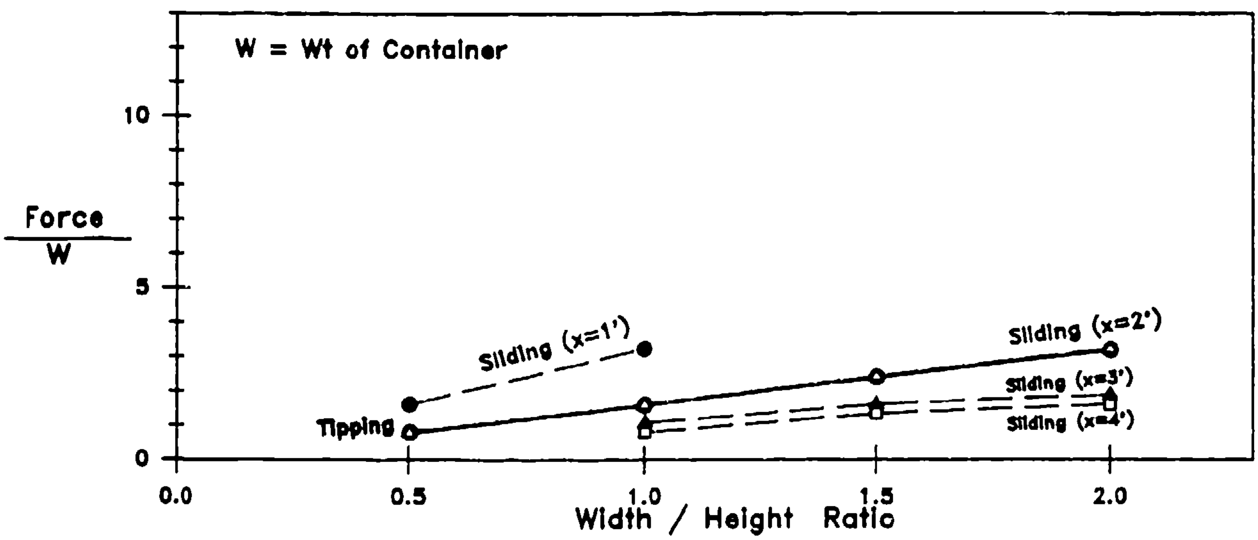
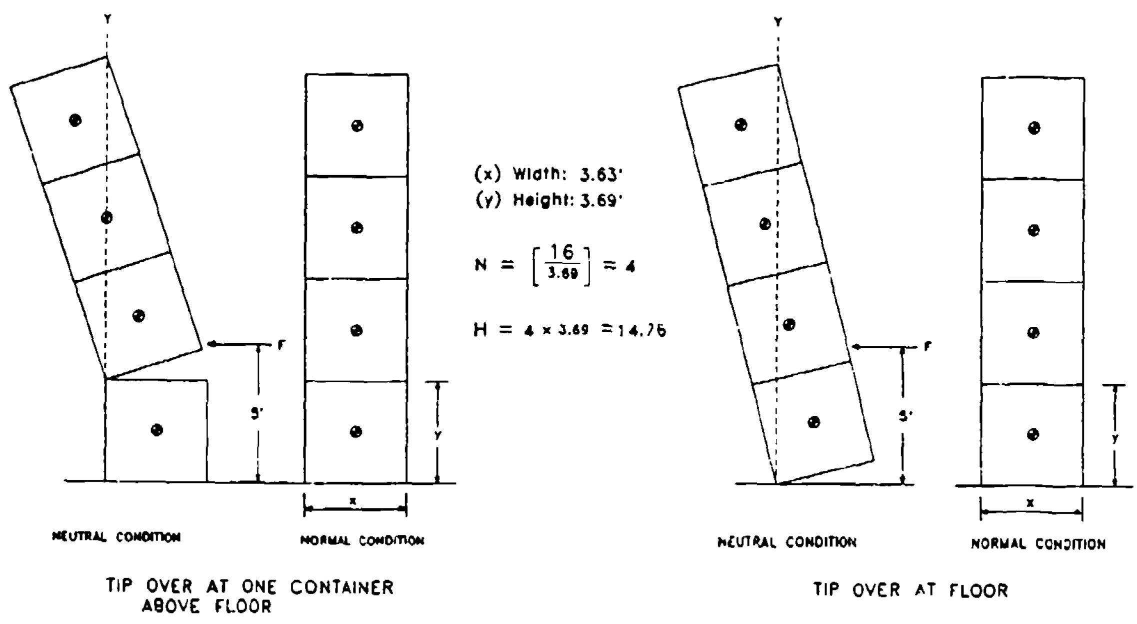


FIGURE 23E
Tipping vs. Sliding Force (μ=0.27, Plastic-Plastic)

Tip Over Location for a Stack of Containers with the Force Applied 5 Feet Above the Floor

From the previous section, it has been noted that with the use of stacking interlock features, tip over will be the dominant mode of failure. The next part of this study compares the amount of force to tip over a stack pivoting at the floor versus a pivot point within the stack. Example 6 presents calculations showing that, when applied 5 feet above the floor, the force required to tip the stack at floor level will be less than tipping from one container level above the floor. Figure 24 shows the relationship between the minimum tipping force on containers, applied at 5 feet above a level floor, and the individual container weight. Each curve has been plotted for a stack made up of one constant container width to height ratio. The solid line indicates the minimum force required to tip the stack at floor level. The dashed line indicates the minimum force required to tip the stack at one container level above the floor. It can be seen that for all container weights, the force to tip the stack at floor level is less than the force required one container above the floor and the difference between the forces increases with container weight.

EXAMPLE 6
Tipping Location for a Stack of Containers With the Force Applied 5 Feet Above the Floor



Tip over at one container above floor.

$$\Sigma M_{Tipping} = (5-y)*F$$

$$\Sigma M_{Restoring} = (\frac{x}{2}) * (N' * W)$$

$$N' = [\frac{16}{y}] - 1$$

Substituting for "N'"

$$\Sigma M_{Restoring} = \left(\frac{x}{2}\right)*\left([\frac{16}{y}]-1\right) * W$$

Equilibrium Condition

$$\Sigma M_{Tipping} = \Sigma M_{Restoring}$$

$$(5-y) * F = \left(\frac{x}{2}\right) * \left([\frac{16}{y}] - 1\right) * W$$

Solving for "F"

$$F = \left(\frac{x}{2}\right)*\frac{\left([\frac{16}{y}] - 1\right)}{(5-y)}*W$$

Tip over at floor.

$$\Sigma M_{Tipping} = 5' * F$$

$$\Sigma M_{Restoring} = (\frac{x}{2}) * (N * W)$$

$$N = [\frac{16}{y}]$$

Substituting for "N"

$$\Sigma M_{Restoring} = \left(\frac{x}{2}\right)*\left([\frac{16}{y}]\right) * W$$

Equilibrium Condition

$$\Sigma M_{Tipping} = \Sigma M_{Restoring}$$

$$5' * F = \left(\frac{x}{2}\right)*\left([\frac{16}{y}] * W\right)$$

Solving for "F"

$$F = \left(\frac{x}{10}\right)*\left([\frac{16}{y}] * W\right)$$

where

F = required force in pounds,

W = weight of individual container in pounds,

x = individual container width in feet,

y = individual container height in feet,

[ ] = quantity inside the brackets must be truncated to a whole number (e.g., 1,2,3,4 . . . etc.),

N' = total of containers within 16-foot limit reduced by one for this calculation.

For example

x = 3.63' y = 3.69'

$$\left[\frac{16}{y}\right] = 4 \qquad \left[\frac{5}{y}\right] = 1$$

F= 4.156W

where

F = required force in pounds,

W = weight of individual container in pounds,

x = individual container width in feet,

y = individual container height in feet,

[ ] = quantity inside the brackets must be truncated to a whole number (e.g., 1,2,3,4 . . . etc.),

N = total number of containers within 16-foot limit.

For example

x = 3.63' y = 3.69'

$$\left[\frac{16}{y}\right] = 4$$

F= 1.452W

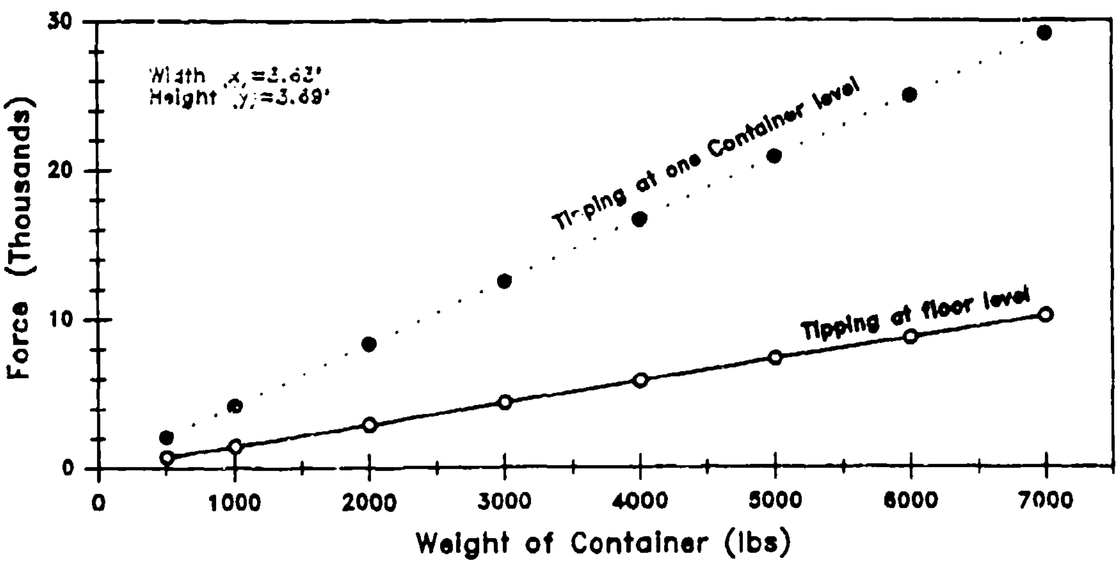


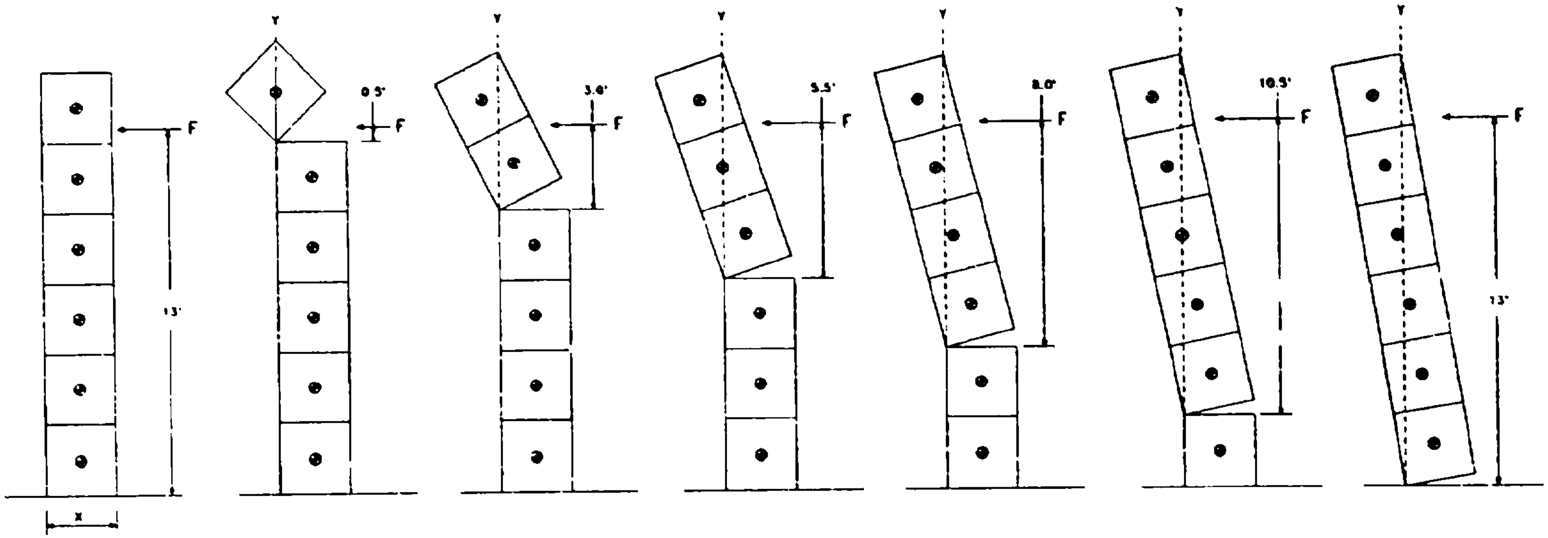
FIGURE 24

Comparison of Minimum Force for Stack Tip Over at Floor Level vs. One Container Above Floor (Force Applied 5 feet Above Floor)

Tip Over Location for a Stack of Containers with the Force Applied Near the Top of the Column

Example 7 presents a series of figures and calculations simulating a forklift truck contact force being applied at an elevation near the top of a stack. Each of the sample calculations use a stack of six 2.5-foot high containers, with the force being applied 13 feet above the floor. The results indicate that the lowest required force occurs when the six containers are pivoted as a group at the floor level.

EXAMPLE 7 Tip Over Location for a Stack of Containers



NORMAL CONDITION

(x) Width: 2.5'
(y) Height: 2.5'

$N = \left[\frac{16}{2.5}\right] = 6$

$H = 6 \times 2.5 = 15$

$\Sigma M_{Tipping} = 0.5' \times F$

$\Sigma M_{Restoring} = \left(\frac{x}{2}\right) \cdot W$

$F = x \cdot W$

$\Sigma M_{Tipping} = 3.0' \times F$

$\Sigma M_{Restoring} = \left(\frac{x}{2}\right) \cdot 2W$

$F = \left(\frac{1}{3}\right) x \cdot W$

$= 0.33\ x \cdot W$

$\Sigma M_{Tipping} = 5.5' \times F$

$\Sigma M_{Restoring} = \left(\frac{x}{2}\right) \cdot 3W$

$F = \left(\frac{3}{11}\right) x \cdot W$

$= 0.27\ x \cdot W$

$\Sigma M_{Tipping} = 8.0' \times F$

$\Sigma M_{Restoring} = \left(\frac{x}{2}\right) \cdot 4W$

$F = \left(\frac{1}{4}\right) x \cdot W$

$= 0.25\ x \cdot W$

$\Sigma M_{Tipping} = 10.5' \times F$

$\Sigma M_{Restoring} = \left(\frac{x}{2}\right) \cdot 5W$

$F = \left(\frac{5}{21}\right) x \cdot W$

$= 0.24\ x \cdot W$

$\Sigma M_{Tipping} = 13' \times F$

$\Sigma M_{Restoring} = \left(\frac{x}{2}\right) \cdot 6W$

$F = \left(\frac{3}{13}\right) x \cdot W$

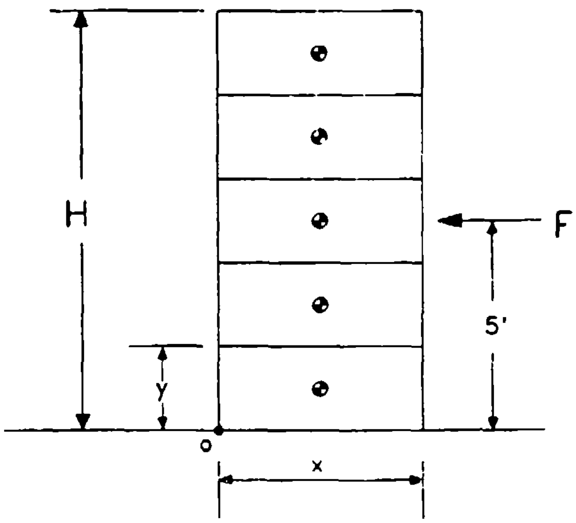
$= 0.23\ x \cdot W$

Comparison of Stack Tip Over Force for a Level or 3-Degree Sloped Floor, Applied 5 Feet Above the Floor

Example 8 shows a sample calculation used to find the force required to tip over a container stack on a level floor. Example 9 shows a similar sample calculation for the tip over force on a ' , 'ainer stack with a floor sloped 3 degrees. Both of these calculations a .. the force at an elevation 5 feet above the floor. The force could have been applied at any elevation, 5 feet was selected to be consistent with the previous calculations. In using any other point of application, the resulting tip over force between a level and 3-degree sloped floor is relative. Figure 25 displays a series of curves relating the minimum tip over force (based on container weight) applied at 5 feet above the floor, to the container width to height ratio. The dashed lines indicate the minimum force required to tip over the stack on a floor sloped 3 degrees. The solid line indicates the minimum force required to tip the stack on a level floor. It can be seen that for all container width to height ratios, the force to tip over the stack on a floor sloped 3 degrees is less than the force required on a level floor. The curves also show that as container width increases the force required for tip over increases, and the effect of floor angle decreases.

Column 7 in table 2 presents the minimum tip over force for each of the containers being studied. This value was calculated using the same equations and limitations as shown in example 9.

EXAMPLE 8
Stack Tip Over Force for a Level Floor, Applied 5 Feet Above the Floor



x = Stacking Width

y = Stacking Height

W = Weight of the individual container

N = Total number of containers within 16' limit, which is truncated (16/y) to a whole number.

H = N·y

F = Min. req'd force to tip over

1. ASSUMPTION

- Floor level.
- Containers are rigidly attached to each other.
- The center of gravity (CG) of the loaded container is a the geometric center of the container.
- The force is being applied parallel to the floor.

2. CALCULATING THE MINIMUM REQUIRED FORCE TO TIP OVER AT 5 FEET ABOVE FLOOR

$$\Sigma M_{Tipping} = 5' * F \quad \Sigma M_{Restoring} = (\frac{x}{2}) * (N * W)$$

3. EQUILIBRIUM CONDITION

$$\Sigma M_{Tipping} = \Sigma M_{Restoring}$$

$$5' * F = (\frac{x}{2}) * (N * W)$$

Solving for "F"

$$F = (\frac{1}{5})*(\frac{x}{2})*(N*W)$$

Substituting for "N"

where

$$N = [\frac{16}{y}]$$

$$F \approx \frac{(16*W)}{10}*(\frac{x}{y})$$

where

F	=	required force in pounds,
W	=	weight of individual container in pounds,
x	=	individual container width in feet,
y	=	individual container height in feet,
[ ]	=	quantity inside the brackets must be truncated to a whole number (e.g., 1,2,3,4 . . . etc.),
N	=	total number of containers within 16-foot limit.

For example

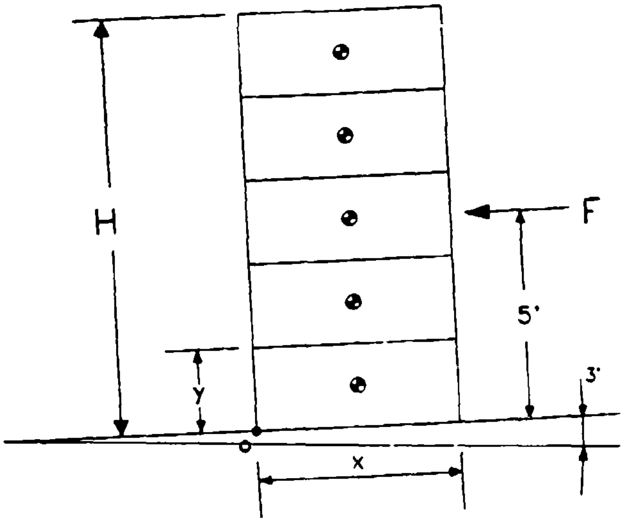
x = 3.63'   y = 3.69'

$$F \approx \frac{16*W}{10}*\left(\frac{x}{y}\right)$$

$$= \frac{16*W}{10}*\left(\frac{3.63}{3.69}\right)$$

$$= 1.574*W$$

EXAMPLE 9
Stack Tip Over Force for a Floor Sloped 3 degrees, Applied 5 Feet Above the Floor



x = Stacking Width

y = Stacking Height

W = Weight of the individual container

N = Total number of containers within 16' limit, which is truncated (16/y) to a whole number.

H = N·y

F = Min. req'd force to tip over

1. ASSUMPTION

- Floor is sloped 3 degrees.
- Containers are rigidly attached to each other.
- The center of gravity (CG) of the loaded container is at the geometric center of the container.
- The force is being applied parallel to the floor.

2. CALCULATING THE MINIMUM REQUIRED FORCE TO TIP OVER AT 5 FEET ABOVE FLOOR

$$\Sigma M_{Tipping} = 5'*F + \left(\frac{N*y}{2}\right)*W*Sin\ 3°$$

$$\Sigma M_{Restoring} = \left(\frac{x}{2}\right)*N*W*Cos\ 3°$$

3. EQUILIBRIUM CONDITION

$$\Sigma M_{Tipping} = \Sigma M_{Restoring}$$

$$5'*F + \frac{(N*y)}{2}*W*Sin\ 3° = \left(\frac{x}{2}\right)*N*W*Cos\ 3°$$

Solving for "F"

$$F = \frac{1}{5}\left((\frac{x}{2})(N*W)Cos\ 3^\circ\ - \left(\frac{N*y}{2}\right)*(N*W)Sin\ 3^\circ \right)$$

Substituting for "N"

where

$$N = [\frac{16}{y}]$$

$$F = \frac{W}{10}\left(x*[\frac{16}{y}]*Cos\ 3^\circ\ - [\frac{16}{y}]*y*[\frac{16}{y}]*Sin\ 3^\circ \right)$$

$$F \approx \frac{16*W}{10}\left((\frac{x}{y})*Cos\ 3^\circ - (\frac{16}{y})*Sin\ 3^\circ \right)$$

where

F	=	required force in pounds,
W	=	weight of individual container in pounds,
x	=	individual container width in feet,
y	=	individual container height in feet,
[ ]	=	quantity inside the brackets must be truncated to a whole number (e.g., 1,2,3,4...etc.),
N	=	total number of containers within 16-foot limit.

For example

x = 3.63' y = 3.69'

$$F \approx \frac{16*W}{10}\left((\frac{x}{y})*\ Cos\ 3^\circ - (\frac{16}{y})*\ Sin\ 3^\circ \right)$$

$$= 1.60\left((\frac{3.63}{3.69})*\ Cos\ 3^\circ - (\frac{16}{3.69})*\ Sin\ 3^\circ \right)$$

$$= 1.209\ *\ W$$

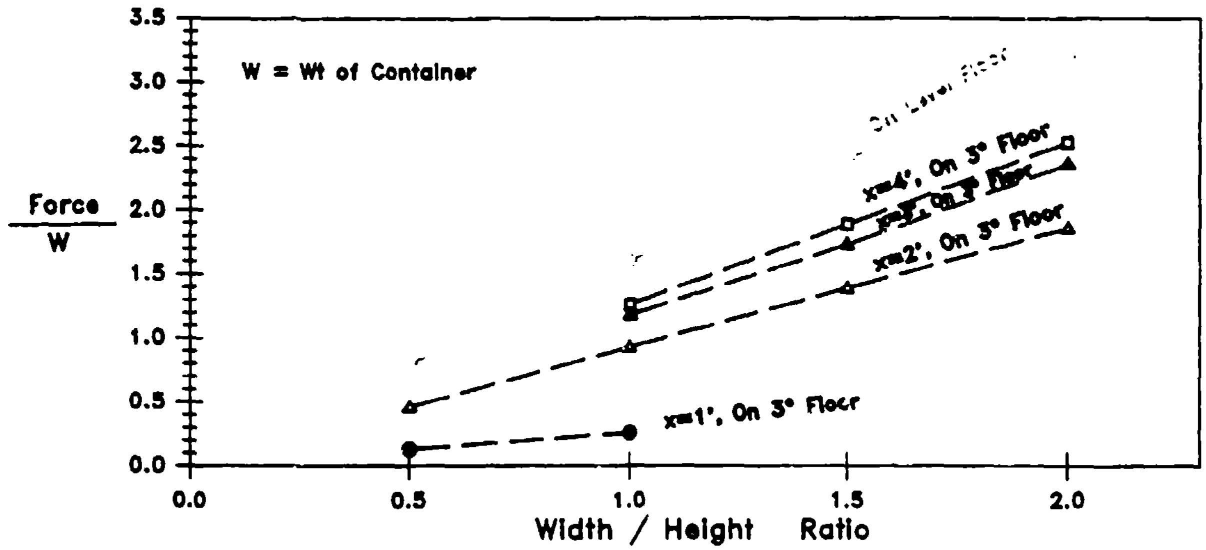


FIGURE 25
Comparison of the Required Minimum Force for Stack Tip Over on Level Floor vs. 3-Degree Sloped Floor (Force Applied 5 feet Above Floor)

Minimum Stack Tip Over Force Compared to Force Possible by Personnel Applied 5 Feet Above Floor With 3-Degree Slope

The values shown in column 7 of table 2 identifies the tip over force, calculated at a height of 5 feet using a 3-degree floor slope. It can be seen that for all containers being evaluated, the lowest tip over force is 150.9 pounds (Mk 399 Mod 0 Container). The maximum amount of force a person could apply from shoulder height was found in MIL-HDBK-759B (table 51). In that table, the horizontal force a person could apply, with one shoulder standing on a high traction surface (μ=.9), was identified as 310 N (67.9 pounds). This indicates that the minimum amount of force calculated to tip over any of the containers in this study is significantly higher than the force possible by a person leaning, or pushing against a stack of containers.

Comparison of the Displacement Required for Tip Over on a Level or 3-Degree Sloped Floor, Measured 5 Feet Above the Floor

Example 10 shows a sample calculation used to find the displacement required to tip over a container stack on a level floor. Example 11 shows a similar sample calculation for the tip over displacement of a container stack with a floor sloped 3 degrees. Both of these calculations consider tip over occurring when the composite center of gravity for a stack passes through the vertical axis of the pivot point. The lateral displacement and force causing tip over to occur has been calculated at an elevation 5 feet above the floor. The force could have been applied at any elevation, 5 feet was selected to be consistent with the previous calculations. A comparison of the example calculations indicates that a stack placed on a 3-degree slope will tip over with approximately 20 percent less displacement than a stack placed on a level floor.

Column 8 in table 2 presents the maximum displacement before tip over occurs for each of the containers being studied. These values were calculated using the same equations and limitations as shown in example 11.

EXAMPLE 10 Required Displacement for Tip Over on a Level Floor

(X) Width: 3.63'
(y) Height: 3.69'

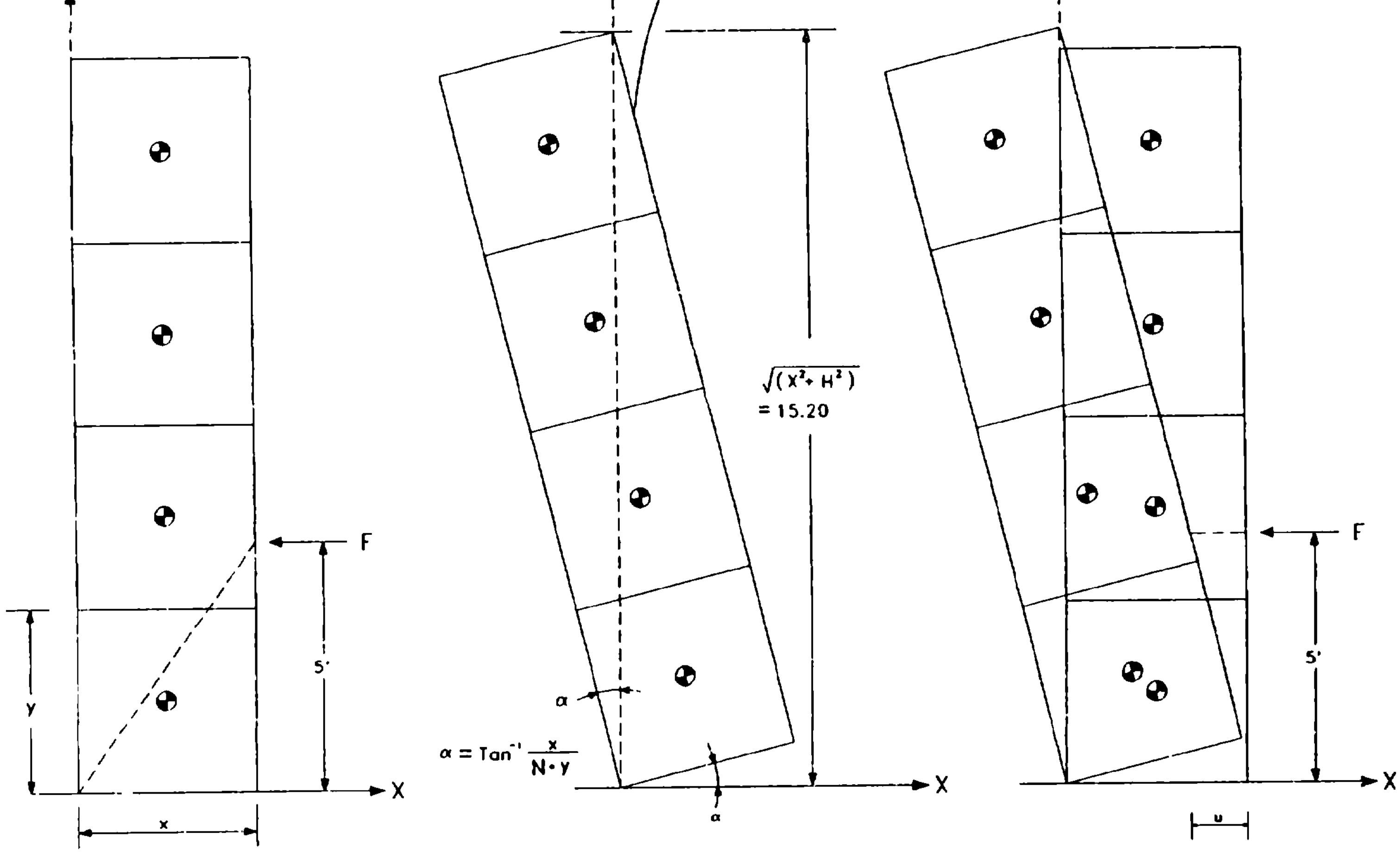
$N = \left[\frac{16}{3.69}\right] = 4$

$H = N \cdot Y$
$= 4 \times 3.69 = 14.76$

Equation $Y = \frac{-1}{\operatorname{Tan}\alpha} X + (X^2 + H^2)^{0.5}$

$= -4.066\,X + 15.20$

When $Y=5$, $X= 2.509$
$u = 3.63 - 2.509$
$= 1.121'$
$= 13.46"$



NORMAL CONDITION

NEUTRAL CONDITION

EXAMPLE 11 Required Displacement for Tip Over on a 3° Sloped Floor

(X) Width: 3.63'
(y) Height: 3.69'

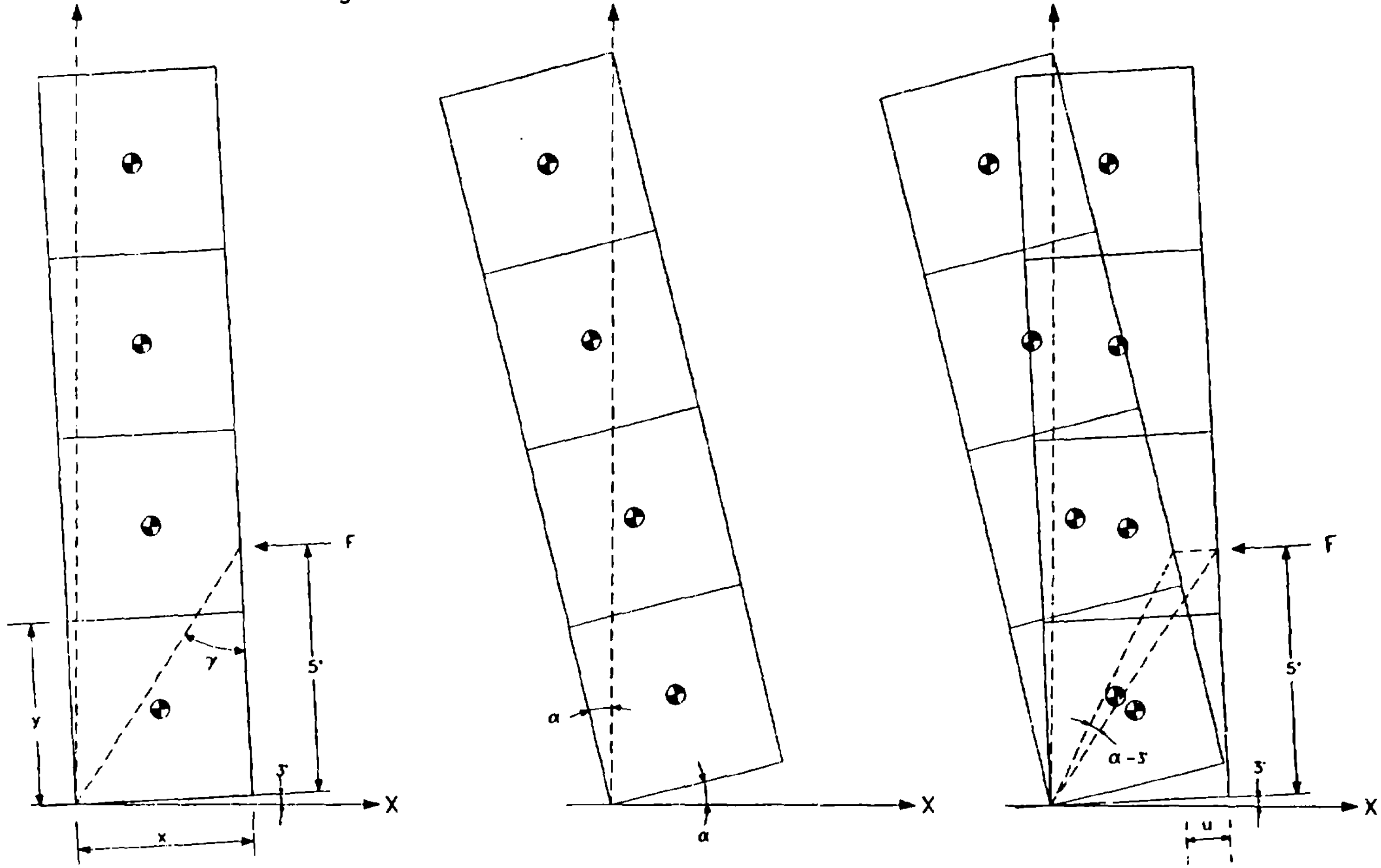
$$N = \left[\frac{16}{3.69}\right] = 4$$

$$\alpha = \mathrm{Tan}^{-1}\frac{x}{N \cdot y}$$

$$u = \sqrt{x^2 + 5^2}\;\frac{\mathrm{Sin}(\alpha-3)\ \mathrm{Sin}(91.5 - \frac{\alpha}{2} - \gamma)}{\mathrm{Sin}(91.5 - \frac{\alpha}{2})\ \mathrm{Sin}(87+\alpha)}$$

$$= 10.67''$$

$$\gamma = \mathrm{Tan}^{-1}\frac{x}{5}$$



NORMAL CONDITION

NEUTRAL CONDITION

Stability Criteria

A review of the container data listed in table 2 reveals that several of the containers at the top of the list have narrow bases, with tip over angles, forces, and displacements relatively low. In real world situations, high stacks of containers having these characteristics tend to sway, appear unstable, and the assumptions used for this analysis become less valid. The values listed in table 2 for the Mk 399 Mod 0 Container illustrating this point are reproduced below:

Item No.	Container Designator	Program	Stacking Width (inches)	Max. No. of Stacked Containers Within 16'	Max. Angle of Floor (degree)	Min. Tipping Force @ 5'on 3° Sloped fl (lb)	Horizontal Displacement at tip over @ 5' on a 3° Sloped fl (in)
52	Mk 399/0	SHRIKE	12.00	11	3.71	150.9	0.75

This situation necessitated the development of a criteria which provides a tolerance on the analytical solution. It was decided that instability would be judged if the displacement at the top of a stack on a 3-degree slope required to cause tipover was less than 50 percent of the container's stacking width. This criteria would result in sufficient visual warning of a stability problem during handling/stacking operations to avoid tip over of a container stack.

The use of this stability criteria required that the lateral displacement be calculated at the top of the upper most container instead of at 5 feet above the floor. Table 2, column 9 shows the top container displacement on a 3-degree slope for impending tip over, and column 10 shows the allowable displacement according to the criteria (50 percent of the container's stacking width). The five containers shown in the shaded area were affected by the application of the stability criteria. In the conclusions section of this study, table 3 presents the recommended stack quantity for each container which includes this stacking limit factor.

SEISMIC CALCULATIONS

Maximum Number of Stacked Containers Limited by Seismic Activity

Due to the specialized nature of seismic forces, this section of the analysis was supplied by the Naval Civil Engineering Laboratory (NCEL), Port Hueneme, California. They developed a sample calculation (example 12) showing the effect of various seismic accelerations on a stack of containers. Using the sample calculation, NCEL then developed a table showing the maximum stacking height for four container models at four values of effective acceleration. The values of effective acceleration are related to seismic risk factor zones. These zones, developed for the Uniform Building Code, are presented on a map of the United States. (See figure 26.) Using the method of calculation supplied by NCEL figure 27 was developed. This figure displays the maximum number of stacked containers possible, using a range of width to height ratios of 0.5 to 2.0. Each of the curves show a trend of increasing stack height with increasing width to height ratios for a constant value of effective acceleration. Additionally, the figure shows that for an increase in effective acceleration the maximum number of containers in a stack is reduced.

Table 4 (Appendix A) identifies the maximum number of stacked containers in the four seismic zones for each container being studied. This value was calculated using the same equation and limitations as shown in example 12. For containers noted in zone 1, the maximum number for a stack, has been reduced to be within the table 3 (Appendix A) limit for maximum numbers of stacked containers.

EXAMPLE 12
Maximum Number of Stacked Containers Limited by Seismic Activity.

In calculating the forces acting on a container stack during seismic activity the overturning moment of the stack at the base is

$$OTM_B = A_a \frac{Ny}{2} \sum_{i=1}^{N} W_i = A_a \frac{Ny}{2}(NW) = N^2 yW \left(\frac{A_a}{2}\right)$$

where

N	-	number of containers in stack,
y	-	height of individual container in feet,
W	-	gross weight of each container including contents in pounds.
A_a	-	effective acceleration for site,
OTM_B	-	overturning moment of stack at base.

The resisting moment of stack at the base is

$$RM_B = NW\frac{x}{2}$$

where

N	=	number of containers in stack,
W	=	gross weight of each container including contents in pounds,
x	=	width of the container in feet,
RM_B	=	resisting moment of stack at base,

In this series of calculations assume that the weight of each container is reduced to .7W due to the effects of vertical acceleration. The ratio of vertical to horizontal acceleration typically range between 1/3 and 2/3.

However, the vertical and horizontal peaks generally do not occur simultaneously.

$$RM_B = .7NW(\frac{x}{2})$$

At incipient overturning of the stack,

$$OTM_B = RM_B$$

$$N^2yW\left(\frac{A_e}{2}\right) = 0.7NW\left(\frac{x}{2}\right)$$

$$N = \left[0.7\left(\frac{x}{A_e y}\right)\right]$$

where

A_e	=	effective acceleration for site,
N	=	number of containers in stack,
x	=	individual container width in feet,
y	=	individual container height in feet,
[ ]	=	quantity inside the brackets must be truncated to a whole number (e.g., 1,2,3,4...etc.).

The following table relates the seismic zones to the effective ground acceleration.

Earthquake Ground Motion	Seismic Zone (Figure 26)	Effective Ground Acceleration A_a(g)
Low	1	0.1
Moderate	2	0.2
High	3	0.3
Severe	4	0.4

Using the effective ground acceleration shown in the above table, the next table presents the maximum number of stacked containers for several models.

N is being calculated for no uplift at base of stack, with (W_{EFF} = 0.7 W)

A_a	MK 535 W=870 pounds x/y=0.743	CNU-536/E W=1320 pounds x/y=1.447	MK 631 W=3590 pounds x/y=0.983	CNU-443A/E W=1246 pounds x/y=0.962
0.1	5	7*	4*	6
0.2	2	5	3	3
0.3	1	3	2	2
0.4	1	2	1	1

*Limited by magazine height envelope of (16 feet)

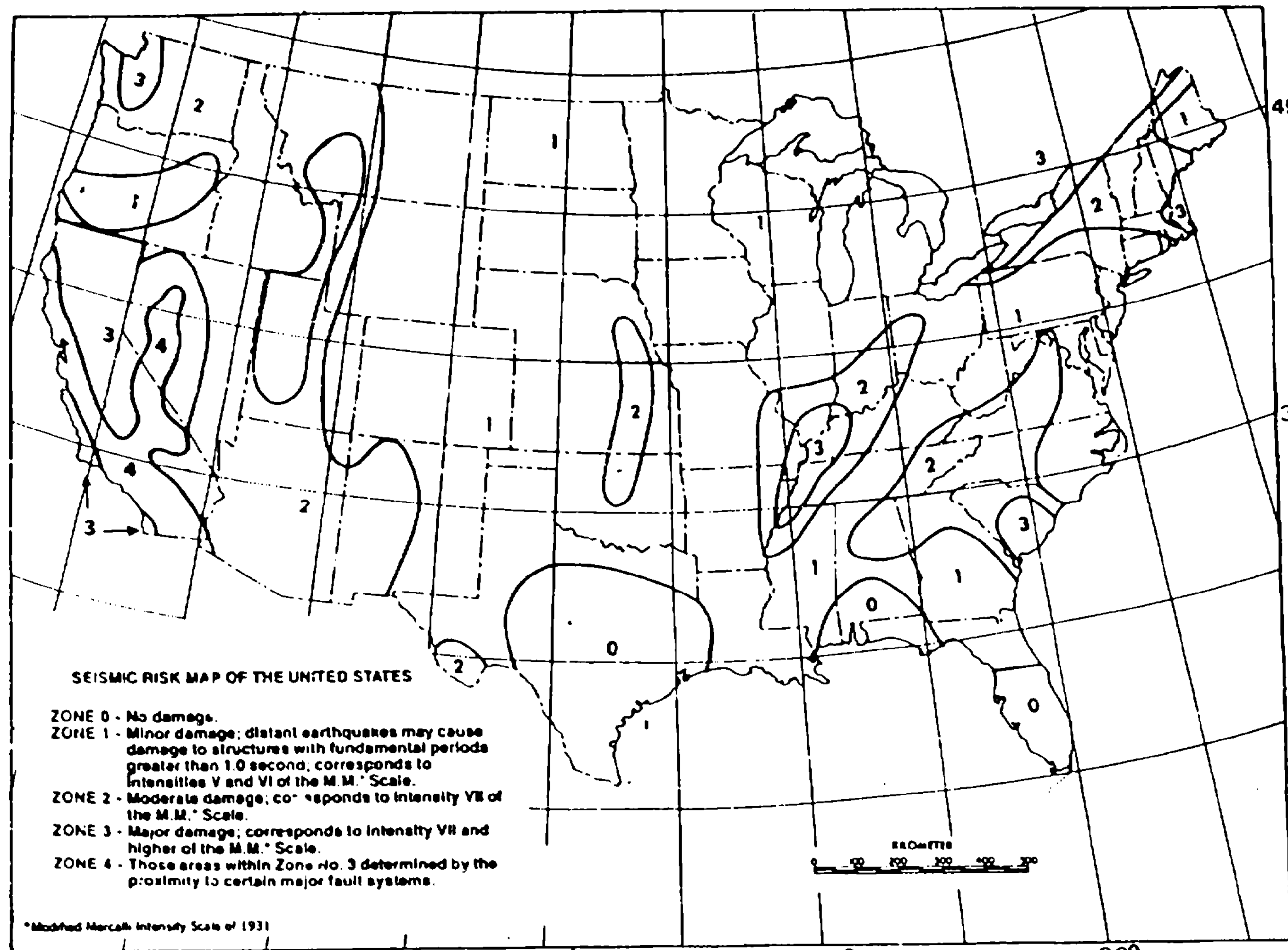


FIGURE 26
Seismic Zone Map of the United States, Uniform Building Code, 1979

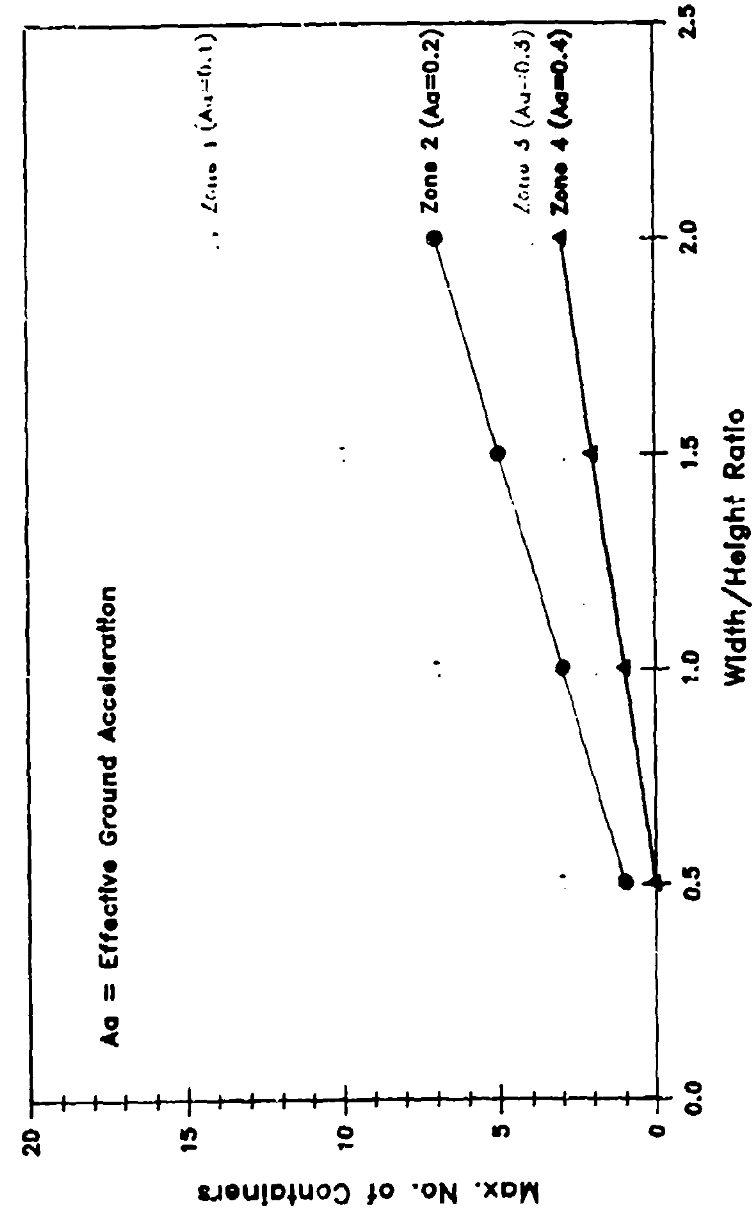


FIGURE 27
Maximum Number of Stacked Containers in Four Different Seismic Zones

SUMMARY OF ANALYSIS

After evaluating the results presented in this study, the following statements can be made:

- Most containers evaluated in this study have their maximum stack height limited by the 16-foot vertical envelope. The remaining containers require stack height reductions due to container development specification limitations or tested strength.

- Due to the self-centering action, the retractable stacking arm containers should not have a large amount of lateral displacement after being placed in a stack.

- In the presence of lateral forces, for most of the container materials studied, tipping is the dominant mode of failure. The exception is for containers made of low coefficient of friction materials (e.g., plastic or fiberglass) where sliding could be the dominant mode of failure depending on the width and stacking interlock.

- For a stack of containers, the lowest required tipping force occurs when all the containers act as a unit and pivot at the floor level.

- The minimum amount of force calculated to tip over any of the containers in this study is significantly higher than the force possible by a person leaning or pushing against a stack of containers.

- Under seismic conditions, an increase in effective acceleration requires a reduction in the maximum number of containers in a stack.

CONCLUSIONS

Based upon the results of this study, the following conclusions can be reached:

- For all magazines, most containers studied can be stacked to the full available height on floors having up to 3 degrees incline without external forces applied.
- For the containers being studied, the force from a person leaning or pushing against the stack is insufficient to cause toppling.
- Without applied lateral forces, the retractable stacking arm style of container will not allow enough lateral displacement to cause tip over.
- To assure safety and stability of narrow containers during handling/stacking operations, the previously noted stability criteria (page 58) must be applied.
- For earthquake prone areas, significant reductions in container stack height, may be required to assure stack stability.

RECOMMENDATIONS

Because stacking stability is significantly affected by procedure and seismic conditions, the recommendations are presented in three groups: Common Procedures, Non-Seismic, and Seismic.

COMMON PROCEDURES FOR STACKING

- When moving and placing containers on a stack, a spotter must be present per NAVSEA OP-5.
- The spotter should alert the forklift operator when the container stack begins to tip.
- Containers should be stacked with interlocking features properly engaged.
- Loaded containers should be in "Code A" condition.
- The magazine floor should not have irregularities which would cause rocking of the base container.

NON-SEISMIC STACKING RECOMMENDATIONS

Table 3 has been compiled without considering seismic conditions. The recommended safe stacking quantity for each container is shown in the right column. The values presented are based on a 16-foot vertical limit.

The following factors have reduced the maximum stack height to a quantity less than allowed by the 16-foot limit:

- Note 1 identifies those containers that have been tested *only* to meet the stacking strength requirements of 49 CFR 178.600 for Performance Oriented Packaging (POP). The stacking strength test under this standard requires a minimum stack height of 3 meters (9.8 feet) as compared to 16 feet for FED-STD-101.

- The stack quantities identified with Note 2 have been reduced to match the known container specification.

- For those container stack quantities identified with Note 3 the number has been reduced using the previously noted stability criteria (page 58).

- The containers identified with Note 4 are wood. For the maximum stack height quantity to be reached the wood must be in good structural condition. Also, due to lack of stacking interlocks the containers must be placed in a vertical line.

The values shown in table 3 are maximum allowable stack quantities which should never be exceeded. Lower stack height quantities may be imposed by local restrictions.

For those containers not covered in this study the following sample calculation has been developed for non-seismic conditions.

Procedure and Sample Calculation to Determine the Maximum Number of Containers Within a 16-Foot Limit (Non-Seismic Condition)

Determining maximum stack height limited by structural strength.

Step 1 Check the container development specification. If the maximum number of containers in a stack is specified, verify with the qualification test report and proceed to step 4 to check stability. If the design stacking strength cannot be verified in the qualification test report, go to step 2.

Step 2 Check the POP test. If the container has been POP tested, use the tested stack quantity as the maximum number of stacked containers. Go to step 4 to check stability. If the container has not been POP tested, go to step 3.

Step 3 The container In-Service Engineering Agent (ISEA) should determine the container's structural strength and maximum stack quantity. After finding those values, go to step 4 to check stability.

Checking and if necessary adjusting stack height for stability.

Step 4 Calculate the maximum number of stacked containers using the following equation:

a.

$$N = [\frac{16}{y}]$$

where

N - total number of containers in a stack within a 16 foot limit,

y - individual container stacking height in feet,

[ ] - quantity inside the brackets must be truncated to a whole number (e.g., 1,2,3,4 . . . etc.).

b. Next, calculate the maximum horizontal displacement (U_{MAX}) and the safe allowable displacement (U_{SAFE}) at the top of the upper most container in the stack. Figure 28 presents both of these displacements in the form of a drawing.

$$U_{SAFE} = 0.5 * x$$

c.

$$\alpha = Tan^{-1}\frac{x}{N*y}$$

d.

$$U_{MAX} = \sqrt{X^2 + (N*y)^2} * \frac{Sin(\alpha - 3)}{Sin(91.5 - \frac{\alpha}{2})} \frac{Sin(91.5 - \frac{3}{2}\alpha)}{Sin(87 + \alpha)}$$

where

N = total number of containers in stack within a 16 foot limit, using whole numbers (e.g., 1,2,3,4 . . . etc.),
x = container stacking width in feet,
y = container stacking height in feet.

e.

if $U_{MAX} > U_{SAFE}$

the maximum number of stacked containers is

$$N = [\frac{16}{y}]$$

if $U_{MAX} \leq U_{SAFE}$, reduce N by 1 and repeat the calculation shown in step 4c to 4e until $U_{MAX} > U_{SAFE}$. The maximum number of stacked containers is the number which satisfies the condition

$$U_{MAX} > U_{SAFE}$$

Step 5 The maximum safe stacking quantity will be the smaller number from steps 1, 2, 3, or 4.

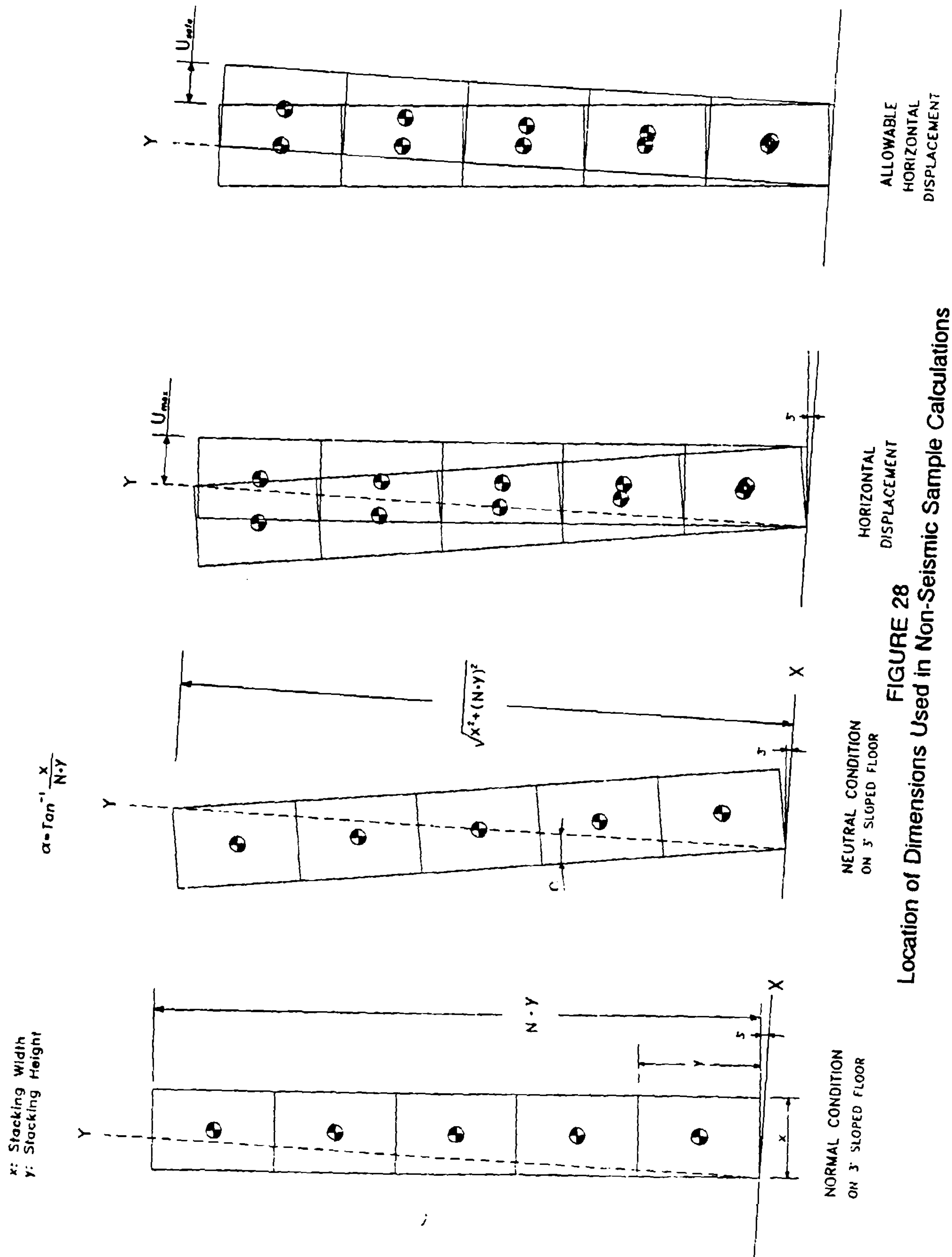


FIGURE 28
Location of Dimensions Used in Non-Seismic Sample Calculations

SEISMIC ZONE STACKING RECOMMENDATIONS

It is realized that the stacking height quantities shown in table 4 for Zone 4 are not realistic for practical storage density. Under seismic conditions, there is a certain amount of tip over risk for all stack heights in all zones.

It is recommended that the local magazine storage authority decide how much risk can be tolerated based on past experience with seismic activity in the area. The local authority should make a decision whether the values shown in table 4 (for seismic conditions) or table 3 (non-seismic conditions) be used. If the values on table 3 are used, in a high seismic activity zone, additional restraint may be desired.

Procedure and Sample Calculation to Determine the Maximum Number of Containers Within a 16 Foot Limit (Seismic Condition)

Step 1 Complete the calculation for the stack quantity under non-seismic conditions.

Step 2 For the location under consideration, select the seismic zone from the map (figure 26).

Step 3 Select the Effective Ground Acceleration (A_a) from the following table.

Earthquake Ground Motion	Seismic Zone (figure 26)	Effective Ground Acceleration A_a (g)
Low	1	0.1
Moderate	2	0.2
High	3	0.3
Severe	4	0.4

Step 4 Calculate the maximum number of stacked containers using the following equation:

$$N_{SEISMIC} = \left[0.7 \left(\frac{x}{A_a\, y} \right) \right]$$

where

$N_{SEISMIC}$	=	number of containers in the stack,
y	=	individual container stacking height in feet,
x	=	individual container stacking width in feet,
A_a	=	effective ground acceleration in g's,
[ ]	=	quantity inside the brackets must be truncated to a whole number (e.g., 1,2,3,4 . . . etc.).

Due to a combination of width to height ratio and seismic zone, if $N_{SEISMIC}$ equals zero, the container under evaluation has the potential to tip over on its side during an earthquake.

Step 5 The maximum safe stacking quantity will be the smaller number from step 4 or the non-seismic stack value.

APPENDIX A

Tables

TABLE 1. CONTAINERS BEING EVALUATED

Item No.	DWG	Container Designator	Program	Overall Width (Inches)	Stacking Width (Inches)	Overall Height (Inches)	Stacking Height (Inches)	W/H Ratio	Gross Wt. (Lbs)	Container Style
1		CNU-124A/E	Phoenix	37.85	37.85	29.50	26.50	1.428	2649	Ext. Frame, Retract. Arms, and Pod
2	+	CNU-131/E	Maverick(Air Force)	25.60	25.60	27.30	27.30	0.938	911	Formed Metal w/ Wood Skid
3	+	CNU-154A/E	Walleye	28.00	28.00	32.00	32.00	0.875	2950	Formed Metal
4	+	CNU-154B/E	Walleye	32.60	32.60	28.70	28.70	1.136	2855	Formed Metal
5	+	CNU-154C/E	Walleye	32.60	32.60	28.70	28.70	1.136	2855	Formed Metal
6		CNU-166/E	Sparrow (Air)	36.00	36.00	26.00	23.00	1.565	2400	Ext. Frame, Retract. Arms, and Pod
7		CNU-167/E	Shrike	36.00	36.00	25.00	22.00	1.636	807	Ext. Frame, Retract. Arms, and Pod
8		CNU-228/E	Phoenix	29.00	19.00	33.75	33.44	0.568	1502	Formed Metal
9		CNU-242A/E	Phoenix	38.00	38.00	31.75	27.63	1.375	2975	Ext. Frame, Retract. Arms, and Pod
10		CNU-242/E	Phoenix	38.00	38.00	31.75	27.63	1.375	3055	Ext. Frame, Retract. Arms, and Pod
11	+	CNU-263/E	Maverick(Air Force)	28.75	28.75	29.50	29.50	0.975	725	Fiberglass
12	+	CNU-287/E	Sidewinder	35.38	35.38	18.63	15.63	2.264	1154	Ext. Frame, Fixed Arms, and Pod
13	+	CNU-295/E	HARM	36.00	36.00	27.81	25.00	1.440	2510	Ext. Frame, Retract. Arms, and Pod
14	+	CNU-305/E	Sparrow	45.00	45.00	21.00	21.00	2.143	2523	ESW
15		CNU-308/E	Tomahawk	33.53	24.70	35.48	34.48	0.716	5518	Fiberglass
16		CNU-319/E	Skipper	36.12	32.12	19.75	19.00	1.691	1513	Formed Metal
17	+	CNU-355/E	HARM	35.00	35.00	22.64	22.64	1.546	2400	ESW
18		CNU-356/E	Walleye	38.00	38.00	31.75	27.60	1.377	3042	Ext. Frame, Retract. Arms, and Pod
19		CNU-399/E	Maverick (Navy)	32.00	27.00	29.70	28.70	0.941	1035	Fiberglass
20		CNU-415A/E	AMRAAM	36.00	36.00	19.87	18.79	1.916	2075	ESW
21		CNU-415/E	AMRAAM	36.00	36.00	19.87	18.79	1.916	1929	ESW
22		CNU-434/E	Sidearm	36.00	36.00	20.13	18.89	1.906	1213	ESW
23		CNU-435/E	Sidewinder	36.00	36.00	20.13	18.89	1.906	1538	ESW
24	+	CNU-436/E	TALD	38.25	38.25	27.00	26.00	1.417	1576	Formed Metal
25		CNU-443/E	Penguin	23.09	23.09	24.38	24.00	0.962	1246	ESW
26		CNU-447/E	Maverick (Navy)	28.18	28.18	30.08	29.26	0.963	1111	ESW
27		CNU-472/E	Maverick (Navy)	32.00	32.00	29.50	29.50	1.085	983	Fiberglass
28	+	CNU-491/E	TALD	33.00	33.00	23.00	22.00	1.435	1355	Molded Plastic

+ CONTAINER DRAWINGS NOT AVAILABLE AT PHST CENTER

TABLE 1. CONTAINERS BEING EVALUATED (Continued)

Item No.	DWG	Container Designator	Program	Overall Width (Inches)	Stacking Width (Inches)	Overall Height (Inches)	Stacking Height (Inches)	W/H Ratio	Gross Wt. (Lbs)	Container Style
29		CNU-536/E	TALD	35.00	35.00	25.68	24.18	1.447	1320	ESW
30	+	MK 12 - 1	Sparrow	36.00	36.00	27.24	27.24	1.322	1827	Ext. Frame, Retract. Arms, and Pod
31		MK 13 - 0	Walleye	38.00	37.07	33.45	33.45	1.108	2950	Ext. Frame, Retract. Arms, and Pod
32		MK 13	Standard VLS	39.40	39.40	41.25	41.25	0.955	4275	Stacking Frame w/ Skid
33	+	MK 14 - 0	Shrike	36.00	36.00	27.24	24.38	1.477	1780	Ext. Frame, Retract. Arms, and Pod
34		MK 14 - 0	Tomahawk VLS	40.12	40.12	43.00	43.00	0.933	6891	Stacking Frame w/ Skid
35		MK 14 - 1	Tomahawk VLS	40.12	40.12	43.00	43.00	0.933	6891	Stacking Frame w/ Skid
36		MK 15 - 0	ASROC VLA	39.40	39.40	41.25	41.25	0.955	4430	Stacking Frame w/ Skid
37		MK 16 - 0	Sidewinder	35.38	35.38	18.60	15.38	2.301	1159	Ext. Frame, Fixed Arms, and Pod
38		MK 183 - 2	ASROC	29.00	19.00	33.02	33.02	0.575	1760	Formed Metal
39		MK 197 - 1	MK46 Torpedo	20.00	16.50	22.00	21.53	0.766	828	Formed Metal
40		MK 199 - 0	SM Extend. Range	27.00	27.00	29.25	29.25	0.923	2060	Formed Metal, Rivited
41		MK 199 - 1	SM Extend. Range	26.57	26.57	29.25	29.25	0.908	2060	Formed Metal, Rivited
42		MK 200 - 0	SM Extend. Range	27.00	27.00	29.25	29.25	0.923	2591	Formed Metal, Rivited
43		MK 200 - 1	SM Extend. Range	27.00	27.00	29.25	29.25	0.923	2591	Formed Metal, Rivited
44		MK 30 - 0	Tomahawk CLS	39.75	39.75	44.00	41.00	0.970	8731	Ext. Frame, Fixed Arms, and Pod
45		MK 30 - 1	Tomahawk CLS	39.75	39.75	44.00	41.00	0.970	8731	Ext. Frame, Fixed Arms, and Pod
46	+	MK 372 - 0	SM Medium Range	28.00		28.40		0.986	2210	Formed Metal
47		MK 372 - 1	SM Medium Range	28.00	28.00	28.75	27.75	1.009	2210	Formed Metal
48		MK 372 - 2	SM Medium Range	28.25	28.25	28.88	27.38	1.032	2210	Formed Metal
49		MK 372 - 3	SM Medium Range	28.00	28.00	28.75	27.75	1.009	2210	Formed Metal
50		MK 372 - 5	SM Medium Range	28.00	28.00	28.75	27.75	1.009	2210	Formed Metal
51		MK 372 - 7	SM Medium Range	28.00	28.00	28.75	27.75	1.009	2210	Formed Metal
52		MK 399 - 0	Shrike	15.28	12.00	17.63	16.81	0.714	688	Formed Metal
53		MK 426 - 0	Walleye	29.18	18.24	32.25	29.86	0.611	1602	Formed Metal
54		MK 426 - 1	Walleye	29.18	18.24	32.25	29.86	0.611	1602	Formed Metal w/ Wood Skid
55		MK 470 - 0	Sparrow (Sea)	21.00	21.00	21.00	20.56	1.021	868	Formed Metal
56		MK 470 - 1	Sparrow (Sea)	21.00	21.00	21.00	20.56	1.021	868	Formed Metal

\+ CONTAINER DRAWINGS NOT AVAILABLE AT PHST CENTER

TABLE 1. CONTAINERS BEING EVALUATED (Continued)

Item No.	DWG	Container Designator	Program	Overall Width (Inches)	Stacking Width (Inches)	Overall Height (Inches)	Stacking Height (Inches)	W/H Ratio	Gross Wt. (Lbs)	Container Style
57		MK 481 - 0	MK 48 Torpedo	28.00	22.00	34.62	33.00	0.667	4484	Formed Metal w/ Wood Skid
58	+	MK 481 - 1	MK 48 Torpedo	30.00		34.00		0.882	4634	Formed Metal
59	+	MK 481 adcap	MK 48 Torpedo	29.75	29.75	34.00	34.00	0.875	4876	Formed Metal
60		MK 535 - 0	MK46 Torpedo	21.31	17.75	24.38	23.88	0.743	870	Formed Metal
61		MK 593 - 0	SM Rocket Motor	20.00	20.00	25.00	25.00	0.800	1159	Wood Crate
62		MK 607 - 0	Harpoon	37.88	37.50	32.63	28.50	1.316	3389	Ext. Frame, Retract. Arms, and Pod
63		MK 608 - 0	ASROC (Harpoon)	28.50	28.50	31.50	31.00	0.919	2500	Formed Metal
64	+	M 611 - 0	HAWK	28.70		41.50		0.905	3351	
65		MK 630 - 0	Harpoon	44.00	43.25	39.25	36.25	1.193	3667	Ext. Frame, Fixed Arms, and Pod
66		MK 631 - 0	Harpoon	45.50	43.50	47.25	44.25	0.983	3590	Ext. Frame, Fixed Arms, and Pod
67		MK 632 - 0	Harpoon	28.00	28.00	28.50	27.50	1.018	2220	Formed Metal
68		MK 686 - 0	SM Extend. Range	27.12	21.62	31.37	29.87	0.724	2759	Fiberglass
69		MK 693 - 0	SM Rocket Motor	20.00	20.00	25.00	25.00	0.800	1362	Wood Crate
70		MK 694 - 0	Harpoon	41.00	30.00	42.50	40.25	0.745	5800	Ext. Frame, Fixed Arms, and Pod
71		MK 714 - 0	MK 50 Torpedo	23.03	23.03	24.38	24.00	0.960	1180	ESW
72		MK 724 - 1	SLAM	37.57	37.57	29.83	29.83	1.259	3924	ESW
73		MK 760 - 0	MK 48 Torpedo	29.75	22.75	34.00	34.00	0.669	4876	Formed Metal w/ Wood Skid

+ CONTAINER DRAWINGS NOT AVAILABLE AT PHST CENTER

TABLE 2. CONTAINER CALCULATIONS

(1) Item No.	(2) Container Designator	(3) Program	(4) Stacking Width (in)	(5) Max. No. of Stacked Containers Within 16'	(6) Max. Angle of Floor (Degree)	(7) Min. Tipping Force @5' on 3° Sloped fl. (lbs)	(8) Horizontal Displacement at tip over @5' on 3° sloped fl. (in)	(9) Hor. Displacement at tip over on 3° sloped fl. (See Note 1) (in)	(10) 50% of Stacking Width (See Note 1) (in)
52	MK 399 - 0	Shrike	12.00	11	3.71	150.9	0.75	2.30	6.00
39	MK 197 - 1	MK46 Torpedo	16.50	8	5.47	459.2	2.57	7.42	8.25
60	MK 535 - 0	MK46 Torpedo	17.75	8	5.31	450.7	2.41	7.69	8.88
53	MK 426 - 0	Walleye	18.24	6	5.81	758.7	2.93	8.78	9.12
54	MK 426 - 1	Walleye	18.24	6	5.81	758.7	2.93	8.78	9.12
8	CNU-228/E	Phoenix	19.00	5	6.48	734.8	3.62	10.14	9.50
38	MK 183 - 2	ASROC	19.00	5	6.56	881.2	3.70	10.25	9.50
61	MK 593 - 0	SM Rocket Motor	20.00	7	6.52	802.1	3.65	10.73	10.00
69	MK 693 - 0	SM Rocket Motor	20.00	7	6.52	942.6	3.65	10.73	10.00
56	MK 470 - 1	Sparrow (Sea)	21.00	9	6.47	762.4	3.60	11.20	10.50
55	MK 470 - 0	Sparrow (Sea)	21.00	9	6.47	762.4	3.60	11.20	10.50
68	MK 686 - 0	SM Extend. Range	21.62	6	6.88	1804.2	4.02	12.10	10.81
57	MK 481 - 0	MK 48 Torpedo	22.00	5	7.59	2899.0	4.75	13.19	11.00
73	MK 760 - 0	MK 48 Torpedo	22.75	5	7.62	3171.5	4.78	13.67	11.38
71	MK 714 - 0	MK 50 Torpedo	23.03	8	6.84	1018.7	3.98	12.83	11.52
25	CNU-443/E	Penguin	23.09	8	6.86	1080.7	3.99	12.89	11.55
15	CNU-308/E	Tomahawk	24.70	5	8.15	4005.6	5.31	15.45	12.35
2	CNU-131/E	Maverick(Air Force)	25.60	7	7.63	831.0	4.78	15.39	12.80
41	MK 199 - 1	SM Extend. Range	26.57	6	8.61	1954.9	5.76	17.11	13.29
40	MK 199 - 0	SM Extend. Range	27.00	6	8.75	2003.3	5.90	17.52	13.50
42	MK 200 - 0	SM Extend. Range	27.00	6	8.75	2519.7	5.90	17.52	13.50
43	MK 200 - 1	SM Extend. Range	27.00	6	8.75	2519.7	5.90	17.52	13.50
19	CNU-399/E	Maverick (Navy)	27.00	6	8.91	1035.8	6.07	17.68	13.50
51	MK 372 - 7	SM Medium Range	28.00	6	9.55	2452.6	6.70	18.92	14.00
50	MK 372 - 5	SM Medium Range	28.00	6	9.55	2452.6	6.70	18.92	14.00
49	MK 372 - 3	SM Medium Range	28.00	6	9.55	2452.6	6.70	18.92	14.00
46	MK 372 - 0	SM Medium Range	28.00	6	9.33	2371.1	6.49	18.74	14.00

TABLE 2. CONTAINER CALCULATIONS (Continued)

(1) Item No.	(2) Container Designator	(3) Program	(4) Stacking Width (in)	(5) Max. No. of Stacked Containers Within 16'	(6) Max. Angle of Floor (Degree)	(7) Min. Tipping Force @5' on 3° Sloped fl. (lbs)	(8) Horizontal Displacement at tip over @5' on 3° sloped fl. (in)	(9) Hor. Displacement at tip over on 3° sloped fl. (See Note 1) (in)	(10) 50% of Stacking Width (See Note 1) (in)
67	MK 632 - 0	Harpoon	28.00	6	9.63	2496.2	6.79	18.99	14.00
47	MK 372 - 1	SM Medium Range	28.00	6	9.55	2452.6	6.70	18.92	14.00
3	CNU-154A/E	Walleye	28.00	6	8.30	2642.2	5.44	17.68	14.00
26	CNU-447/E	Maverick (Navy)	28.18	6	9.12	1151.4	6.27	18.66	14.09
48	MK 372 - 2	SM Medium Range	28.25	7	8.38	2347.9	5.53	17.94	14.13
63	MK 608 - 0	ASROC (Harpoon)	28.50	6	8.71	2416.3	5.86	18.46	14.25
64	M 611 - 0	HAWK	28.70	4	9.81	2580.4	6.96	19.62	14.35
11	CNU-263/E	Maverick(Air Force)	28.75	6	9.23	764.7	6.38	19.14	14.38
59	MK 481 adcap	MK 48 Torpedo	29.75	5	9.93	4775.5	7.07	20.43	14.88
58	MK 481 - 1	MK 48 Torpedo	30.00	5	10.01	4593.0	7.15	20.67	15.00
70	MK 694 - 0	Harpoon	30.00	4	10.56	4964.6	7.70	21.09	15.00
27	CNU-472/E	Maverick (Navy)	32.00	6	10.25	1209.9	7.37	22.25	16.00
16	CNU-319/E	Skipper	32.12	10	9.60	2819.9	6.72	21.75	16.06
5	CNU-154C/E	Walleye	32.60	6	10.72	3747.2	7.84	23.05	16.30
4	CNU-154B/E	Walleye	32.60	6	10.72	3747.2	7.84	23.05	16.30
28	CNU-491/E	TALD	33.00	8	10.62	2339.8	7.73	23.25	16.50
29	CNU-536/E	TALD	35.00	7	11.68	2279.1	8.76	25.44	17.50
17	CNU-355/E	HARM	35.00	8	10.94	4320.5	8.03	24.91	17.50
37	MK 16 - 0	Sidewinder	35.38	12	10.85	3096.2	7.94	25.12	17.69
12	CNU-287/E	Sidewinder	35.38	12	10.68	3014.2	7.77	24.98	17.69
30	MK 12 - 1	Sparrow	36.00	7	10.69	2787.0	7.78	25.43	18.00
22	CNU-434/E	Sidearm	36.00	10	10.79	2677.9	7.87	25.51	18.00
23	CNU-435/E	Sidewinder	36.00	10	10.79	3395.4	7.87	25.51	18.00
13	CNU-295/E	HARM	36.00	7	11.62	4303.8	8.69	26.13	18.00
21	CNU-415/E	AMRAAM	36.00	10	10.85	4289.9	7.93	25.55	18.00
20	CNU-415A/E	AMRAAM	36.00	10	10.85	4614.6	7.93	25.55	18.00
33	MK 14 - 0	Shrike	36.00	7	11.91	3156.3	8.97	26.32	18.00

TABLE 2. CONTAINER CALCULATIONS (Continued)

(1) Item No.	(2) Container Designator	(3) Program	(4) Stacking Width (in)	(5) Max. No. of Stacked Containers Within 16'	(6) Max. Angle of Floor (Degree)	(7) Min. Tipping Force @5' on 3° Sloped fl. (lbs)	(8) Horizontal Displacement at tip over @5' on 3° sloped fl. (in)	(9) Hor. Displacement at tip over on 3° sloped fl. (See Note 1) (in)	(10) 50% of Stacking Width (See Note 1) (in)
7	CNU-167/E	Shrike	36.00	8	11.56	1569.4	8.63	26.09	18.00
6	CNU-166/E	Sparrow (Air)	36.00	8	11.07	4394.4	8.15	25.73	18.00
31	MK 13 - 0	Walleye	37.07	5	12.50	3988.5	9.52	27.46	18.54
62	MK 607 - 0	Harpoon	37.50	6	12.37	5422.2	9.39	27.71	18.75
72	MK 724 - 1	SLAM	37.57	6	11.85	5925.1	8.89	27.43	18.79
1	CNU-124A/E	Phoenix	37.85	7	11.53	4492.7	8.58	27.41	18.93
10	CNU-242/E	Phoenix	38.00	6	12.91	5178.4	9.91	28.39	19.00
18	CNU-356/E	Walleye	38.00	6	12.92	5163.7	9.92	28.40	19.00
9	CNU-242A/E	Phoenix	38.00	6	12.91	5042.8	9.91	28.39	19.00
24	CNU-436/E	TALD	38.25	7	11.87	2780.8	8.90	27.94	19.13
36	MK 15 - 0	ASROC VLA	39.40	4	13.43	5277.0	10.38	29.71	19.70
32	MK 13	Standard VLS	39.40	4	13.43	5092.4	10.38	29.71	19.70
44	MK 30 - 0	Tomahawk CLS	39.75	4	13.62	10600.7	10.56	30.07	19.88
45	MK 30 - 1	Tomahawk CLS	39.75	4	13.62	10600.7	10.56	30.07	19.88
34	MK 14 - 0	Tomahawk VLS	40.12	4	13.13	7964.9	10.08	30.09	20.06
35	MK 14 - 1	Tomahawk VLS	40.12	4	13.13	7964.9	10.08	30.09	20.06
65	MK 630 - 0	Harpoon	43.25	5	13.42	5455.3	10.31	32.61	21.63
66	MK 631 - 0	Harpoon	43.50	4	13.81	4436.4	10.67	33.00	21.75
14	CNU-305/E	Sparrow	45.00	9	13.39	6737.0	10.25	33.91	22.50

Notes:

1. Horizontal Displacement is calculated at the top of the upper most container.

2. The Horizontal Displacement of shaded Containers at the top of the upper most container on 3° sloped floor is less than the Allowable Horizontal Displacement. Therefore, the Maximum Number of Stacked Containers within 16' should be reduced. See Table 3.

TABLE 3. RECOMMENDED NUMBER OF STACKED LOADED CONTAINERS IN MAGAZINES (NON-SEISMIC CONDITIONS)

Item No.	Container Designator	Program	Stacking Width (in)	Stacking Height (in)	Gross Wt. (lbs)	Recommended Maximum Number of Stacked Containers *(Note #)	
1	CNU-124A/E	Phoenix	37.85	26.50	2649		7
2	CNU-131/E	Maverick(Air Force)	25.60	27.30	911	*(1)	4
3	CNU-154A/E	Walleye	28.00	32.00	2950		6
4	CNU-154B/E	Walleye	32.60	28.70	2855		6
5	CNU-154C/E	Walleye	32.60	28.70	2855		6
6	CNU-166/E	Sparrow (Air)	36.00	23.00	2400		8
7	CNU-167/E	Shrike	36.00	22.00	807		8
8	CNU-228/E	Phoenix	19.00	33.44	1502		5
9	CNU-242A/E	Phoenix	38.00	27.63	2975		6
10	CNU-242/E	Phoenix	38.00	27.63	3055		6
11	CNU-263/E	Maverick(Air Force)	28.75	29.50	725	*(1)	4
12	CNU-287/E	Sidewinder	35.38	15.63	1154		12
13	CNU-295/E	HARM	36.00	25.00	2510		7
14	CNU-305/E	Sparrow	45.00	21.00	2523		9
15	CNU-308/E	Tomahawk	24.70	34.48	5518		5
16	CNU-319/E	Skipper	32.12	19.00	1513		10
17	CNU-355/E	HARM	35.00	22.64	2400		8
18	CNU-356/E	Walleye	38.00	27.60	3042		6
19	CNU-399/E	Maverick (Navy)	27.00	28.70	1035	*(1)	4
20	CNU-415A/E	AMRAAM	36.00	18.79	2075		10
21	CNU-415/E	AMRAAM	36.00	18.79	1929		10
22	CNU-434/E	Sidearm	36.00	18.89	1213	*(1)	6
23	CNU-435/E	Sidewinder	36.00	18.89	1538	*(1)	6
24	CNU-436/E	TALD	38.25	26.00	1576		7
25	CNU-443/E	Penguin	23.09	24.00	1246		8
26	CNU-447/E	Maverick (Navy)	28.18	29.26	1111		6
27	CNU-472/E	Maverick (Navy)	32.00	29.50	983	*(1)	4
28	CNU-491/E	TALD	33.00	22.00	1355	*(1)	4
29	CNU-536/E	TALD	35.00	24.18	1320		7
30	MK 12 - 1	Sparrow	36.00	27.24	1827		7

TABLE 3. RECOMMENDED NUMBER OF STACKED LOADED CONTAINERS IN MAGAZINES (NON-SEISMIC CONDITIONS) (Continued)

Item No.	Container Designator	Program	Stacking Width (in)	Stacking Height (in)	Gross Wt. (lbs)	Recommended Maximum Number of Stacked Containers *(Note #)	
31	MK 13 - 0	Walleye	37.07	33.45	2950		5
32	MK 13	Standard VLS	39.40	41.25	4275		4
33	MK 14 - 0	Shrike	36.00	24.38	1780		7
34	MK 14 - 0	Tomahawk VLS	40.12	43.00	6891		4
35	MK 14 - 1	Tomahawk VLS	40.12	43.00	6891		4
36	MK 15 - 0	ASROC VLA	39.40	41.25	4430		4
37	MK 16 - 0	Sidewinder	35.38	15.38	1159		12
38	MK 183 - 2	ASROC	19.00	33.02	1760	*(2)	4
39	MK 197 - 1	MK46 Torpedo	16.50	21.53	828	*(3)	7
40	MK 199 - 0	SM Extend. Range	27.00	29.25	2060		6
41	MK 199 - 1	SM Extend. Range	26.57	29.25	2060		6
42	MK 200 - 0	SM Extend. Range	27.00	29.25	2591		6
43	MK 200 - 1	SM Extend. Range	27.00	29.25	2591		6
44	MK 30 - 0	Tomahawk CLS	39.75	41.00	8731		4
45	MK 30 - 1	Tomahawk CLS	39.75	41.00	8731		4
46	MK 372 - 0	SM Medium Range	28.00	28.40	2210		6
47	MK 372 - 1	SM Medium Range	28.00	27.75	2210		6
48	MK 372 - 2	SM Medium Range	28.25	27.38	2210		7
49	MK 372 - 3	SM Medium Range	28.00	27.75	2210		6
50	MK 372 - 5	SM Medium Range	28.00	27.75	2210		6
51	MK 372 - 7	SM Medium Range	28.00	27.75	2210		6
52	MK 399 - 0	Shrike	12.00	16.81	688	*(3)	6
53	MK 426 - 0	Walleye	18.24	29.86	1602	*(3)	5
54	MK 426 - 1	Walleye	18.24	29.86	1602	*(3)	5
55	MK 470 - 0	Sparrow (Sea)	21.00	20.56	868		9
56	MK 470 - 1	Sparrow (Sea)	21.00	20.56	868		9
57	MK 481 - 0	MK 48 Torpedo	22.00	33.00	4484	*(2)	4
58	MK 481 - 1	MK 48 Torpedo	30.00	34.00	4634		5
59	MK 481 adcap	MK 48 Torpedo	29.75	34.00	4876		5
60	MK 535 - 0	MK46 Torpedo	17.75	23.88	870	*(3)	6

TABLE 3. RECOMMENDED NUMBER OF STACKED LOADED CONTAINERS IN MAGAZINES (NON-SEISMIC CONDITIONS)
(Continued)

Item No.	Container Designator	Program	Stacking Width (in)	Stacking Height (in)	Gross Wt. (lbs)	Recommended Maximum Number of Stacked Containers *(Note #)	
61	MK 593 - 0	SM Rocket Motor	20.00	25.00	1159	*(4)	7
62	MK 607 - 0	Harpoon	37.50	28.50	3389	*(2)	5
63	MK 608 - 0	ASROC (Harpoon)	28.50	31.00	2500	*(2)	4
64	M 611 - 0	HAWK	28.70	41.50	3351		4
65	MK 630 - 0	Harpoon	43.25	36.25	3667		5
66	MK 631 - 0	Harpoon	43.50	44.25	3590		4
67	MK 632 - 0	Harpoon	28.00	27.50	2220		6
68	MK 686 - 0	SM Extend. Range	21.62	29.87	2759	*(2)	4
69	MK 693 - 0	SM Rocket Motor	20.00	25.00	1362	*(4)	7
70	MK 694 - 0	Harpoon	30.00	40.25	5800		4
71	MK 714 - 0	MK 50 Torpedo	23.03	24.00	1180		8
72	MK 724 - 1	SLAM	37.57	29.83	3924		6
73	MK 760 - 0	MK 48 Torpedo	22.75	34.00	4876		5

* Notes:

1. POP (Performance Oriented Packaging) tested.

2. Based on the container development specification.

3. The Number of Stacked Containers has been reduced considering the Safe Allowable Horizontal Displacement and the Maximum Allowable Displacement in Table 2.

4. This container is made of wood. To achieve the maximum stack height quantity, the wood must be in a good structural condition. Also, due to lack of stacking interlocks the containers must be placed in a vertical line.

TABLE 4. THE MAXIMUM NUMBER OF STACKED LOADED CONTAINERS IN MAGAZINES (SEISMIC CONDITIONS)

Item No.	Container Designator	Program	Ratio x/y	Max. No. of Stacked Containers Under the Seismic Condition Zone 1	Zone 2	Zone 3	Zone 4
1	CNU-124A/E	Phoenix	1.428	* 7	4	3	2
2	CNU-131/E	Maverick(Air Force)	0.938	* 4	3	2	1
3	CNU-154A/E	Walleye	0.875	6	3	2	1
4	CNU-154B/E	Walleye	1.136	* 6	3	2	1
5	CNU-154C/E	Walleye	1.136	* 6	3	2	1
6	CNU-166/E	Sparrow (Air)	1.565	* 8	5	3	2
7	CNU-167/E	Shrike	1.636	* 8	5	3	2
8	CNU-228/E	Phoenix	0.568	3	1	1	** 0
9	CNU-242A/E	Phoenix	1.375	* 6	4	3	2
10	CNU-242/E	Phoenix	1.375	* 6	4	3	2
11	CNU-263/E	Maverick(Air Force)	0.975	* 4	3	2	1
12	CNU-287/E	Sidewinder	2.264	* 12	7	5	3
13	CNU-295/E	HARM	1.440	* 7	5	3	2
14	CNU-305/E	Sparrow	2.143	* 9	7	5	3
15	CNU-306/E	Tomahawk	0.716	5	2	1	1
16	CNU-319/E	Skipper	1.691	* 10	5	3	2
17	CNU-355/E	HARM	1.546	* 8	5	3	2
18	CNU-356/E	Walleye	1.377	* 6	4	3	2
19	CNU-399/E	Maverick (Navy)	0.941	* 4	3	2	1
20	CNU-415A/E	AMRAAM	1.916	* 10	6	4	3
21	CNU-415/E	AMRAAM	1.916	* 10	6	4	3
22	CNU-434/E	Sidearm	1.906	* 6	6	4	3
23	CNU-435/E	Sidewinder	1.906	* 6	6	4	3
24	CNU-436/E	TALD	1.471	7	5	3	2
25	CNU-443/E	Penguin	0.962	6	3	2	1
26	CNU-447/E	Maverick (Navy)	0.963	6	3	2	1
27	CNU-472/E	Maverick (Navy)	1.085	* 4	3	2	1
28	CNU-491/E	TALD	1.500	* 8	5	3	2
29	CNU-536/E	TALD	1.447	* 7	5	3	2
30	MK 12 - 1	Sparrow	1.322	* 7	4	3	2
31	MK 13 - 0	Walleye	1.108	* 5	3	2	1
32	MK 13	Standard VLS	0.955	* 4	3	2	1
33	MK 14 - 0	Shrike	1.477	* 7	5	3	2
34	MK 14 - 0	Tomahawk VLS	0.933	* 4	3	2	1
35	MK 14 - 1	Tomahawk VLS	0.933	* 4	3	2	1
36	MK 15 - 0	ASROC VLA	0.955	* 4	3	2	1
37	MK 16 - 0	Sidewinder	2.301	* 12	8	5	4
38	MK 183 - 2	ASROC	0.575	4	2	1	1
39	MK 197 - 1	MK46 Torpedo	0.766	5	2	1	1
40	MK 199 - 0	SM Extend. Range	0.923	6	3	2	1
41	MK 199 - 1	SM Extend. Range	0.908	6	3	2	1
42	MK 200 - 0	SM Extend. Range	0.923	6	3	2	1
43	MK 200 - 1	SM Extend. Range	0.923	6	3	2	1

TABLE 4. THE MAXIMUM NUMBER OF STACKED LOADED CONTAINERS IN MAGAZINES (SEISMIC CONDITIONS) (Continued)

Item No.	Container Designator	Program	Ratio x/y	Max. No. of Stacked Containers Under the Seismic Condition			
				Zone 1	Zone 2	Zone 3	Zone 4
44	MK 30 - 0	Tomahawk CLS	0.970	* 4	3	2	1
45	MK 30 - 1	Tomahawk CLS	0.970	* 4	3	2	1
46	MK 372 - 0	SM Medium Range	0.986	6	3	2	1
47	MK 372 - 1	SM Medium Range	1.009	* 6	3	2	1
48	MK 372 - 2	SM Medium Range	1.032	7	3	2	1
49	MK 372 - 3	SM Medium Range	1.009	* 6	3	2	1
50	MK 372 - 5	SM Medium Range	1.009	* 6	3	2	1
51	MK 372 - 7	SM Medium Range	1.009	* 6	3	2	1
52	MK 399 - 0	Shrike	0.714	4	2	1	1
53	MK 426 - 0	Walleye	0.611	4	2	1	1
54	MK 426 - 1	Walleye	0.611	4	2	1	1
55	MK 470 - 0	Sparrow (Sea)	1.021	7	3	2	1
56	MK 470 - 1	Sparrow (Sea)	1.021	7	3	2	1
57	MK 481 - 0	MK 48 Torpedo	0.667	4	2	1	1
58	MK 481 - 1	MK 48 Torpedo	0.882	* 5	3	2	1
59	MK 481 adcap	MK 48 Torpedo	0.875	* 5	3	2	1
60	MK 535 - 0	MK46 Torpedo	0.743	5	2	1	1
61	MK 593 - 0	SM Rocket Motor	0.800	5	2	1	1
62	MK 607 - 0	Harpoon	1.316	* 5	4	3	2
63	MK 608 - 0	ASROC (Harpoon)	0.919	* 4	3	2	1
64	M 611 - 0	HAWK	0.692	4	2	1	1
65	MK 630 - 0	Harpoon	1.193	* 5	4	2	2
66	MK 631 - 0	Harpoon	0.983	* 4	3	2	1
67	MK 632 - 0	Harpoon	1.018	* 6	3	2	1
68	MK 686 - 0	SM Extend. Range	0.724	* 4	2	1	1
69	MK 693 - 0	SM Rocket Motor	0.800	5	2	1	1
70	MK 694 - 0	Harpoon	0.745	* 4	2	1	1
71	MK 714 - 0	MK 50 Torpedo	0.960	6	3	2	1
72	MK 724 - 1	SLAM	1.259	* 6	4	2	2
73	MK 760 - 0	MK 48 Torpedo	0.669	4	2	1	1

Notes:

* The Maximum Number of Stacked Containers in Seismic Zone 1 has been reduced to be within the Table 3 limit for the Maximum Number of Stacked Containers.

** Due to the combination of Width to Height Ratio and seismic zone, the noted container has the potential to tip over on its side during an earthquake.